

The Effects of Environmental Boundaries on Event Segmentation and Memory



By

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A thesis submitted in partial fulfilment of the requirements of the University of East Anglia

for the degree of

Doctor of Philosophy

Research undertaken in the School of Psychology, University of East Anglia November

2025

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Abstract

Event segmentation is the process in which we break up continuous streams of information from our everyday life into discrete units of memory. The most dominant model currently exploring event segmentation in visual experience, the Event Horizon Model, acknowledges the complexities of segmenting conscious experience; however, research surrounding the model falls short for representing the effects event segmentation can have on memory performance. Research often reports a forgetting effect of event segmentation on memory performance; however, there are some concerns for how representative these findings are of real-world experience. The project primarily utilised Virtual Reality to conduct experiments to create a research paradigm that would produce more ecologically valid research than previously conducted on the topic. Chapter 2 examines the current research surrounding event segmentation and tries to replicate the forgetting results commonly reported, but in more ecologically valid test conditions. Upon not being able to reliably find forgetting effects for event segmentation, Chapter 3 explored the concepts of environments and boundaries. To draw out memory effects, these features of the space were manipulated to be highly contrasting, testing memory performance for two similar and two distinct spaces in one experiment, and assessing differences in memory performance across a doorway and corridor segmenting a space. Chapter 4 then expands on our testing methods to assess whether there are other cognitive processes, namely route learning, that are influenced by event segmentation. Participants learned a route and identified skips in a sequence of images depicting the route, with the sequence either having a high or low segmentation focus, finding an influence of event segmentation on route learning. Chapter 5 took a different approach, utilising both qualitative and quantitative methods to understand the thought process behind segmenting behaviours, where participants had to draw maps of an explored space, and answer questions based on the map they drew. Familiarity with the environment resulted in a change of attitudes towards participants, with participants responding with confidence to high familiarity spaces, and uncertainty in low familiarity spaces. The concluding chapter consolidates these findings into a series of recommendations to amend the Event Horizon Model, which take more consideration of individual differences, as well as possible variations in spaces. Methodological recommendations were also made, highlighting the importance of ecological validity, and emphasising the importance of results which can be found and applied to real-world scenarios.

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Glossary

Term	Description
Attention allocation	How it is determined what attention is focused on and divided between
Boundaries	The outer limits of an event which defines the confines of a given event and marks where one event ends and another begins
Chunking	The grouping together of information to make it easier to remember
Contextual cue	Information provided from the wider space to inform about a more select stimuli
Ecological validity	The relationship between real world phenomena and its manifestation in experimental conditions
Environment	The surrounding environment that may not be limited to a single event or may comprise of multiple spaces and scenes
Event	A discreet unit of memory that can be defined by a singular space or goal
Event Horizon Model	The dominant theory of event segmentation in spatial memory and recognition as developed by Radvansky (2012)
Gist	The initial perception of a space from the first visual exposure to a space
Goal-directed event	A discreet unit of memory that is categorised by the establishment and completion of a goal and its associated behaviours
Immersion	A level of mental involvement in a given experience
Landmark	A significant feature of an environment which can easily be used in relation to other less significant objects and features in an environment
Local Object	An object contained within an environment that is not important to the definition of an environment
Local Processing	The encoding and perception of smaller, more fine-grained aspects of an environment
Prediction-error	A threshold that is maintained by expectations that when violated, expectations must be adjusted
Representations	Holding information in the brain which correspond to an object or feature of the external world
Rote memory	The memorisation of information through repetition without necessarily understanding
Scenes	The visual information present for a defined event, which can consist of part of a space, or multiple spaces if the scene is defined by goal orientated behaviour
Scene complexity	How easy or hard it is to understand a scene with the number of components there are to process
Scene perception	How a given scene is understood by the individual using sensory information (visual and auditory information)
Scene Processing	How information within a scene is understood by the individual

	(how a scene is remembered or understood)
Semantic information	Meaningful content of knowledge and concepts, enabling understanding, communication, and interpretation
Spaces	A single unified space that is contained within established physical boundaries (for example, a room)

Acknowledgements

First, I would like to thank my supervisors Dr. George Malcom and Dr. Louise Ewing. This project was hit with a lot of hurdles, especially when it came to health issues, and the two of you gave me nothing but patience and compassion during all of the trying times. This project would not have been possible without either of you and I cannot thank you enough.

I would also like to thank Richard Carey-Knight for being a great lab technician. You were always around when things went wrong and were able to solve them quickly. You always made working in the lab a fun time, whether it was talking about work, or just taking some time to relax and catch up

Next, I would like to thank Dr. Ian Norman for helping with the qualitative aspects of this project. None of the research team had much experience with qualitative research, and you took the time to sit with us, walk us through it and were always happy to help. The final experiment in this project would not have ran as smoothly without your contribution.

I would also like to thank all the doctors, nurses and surgeons in the Norfolk and Norwich University Hospital's Ophthalmology department. I lost in late 2021 and through all your tireless efforts, and countless surgeries, two years later I regained some of my vision, and I cannot express my gratitude enough.

To all the friends I made throughout this PhD, whether it was a chat in the office or some social time to decompress, you all helped me make it through. A PhD is hard, and you all made it a much easier experience.

And finally, I would like to thank my partner, Ben. Your support means so much to me, from reading my chapters before I sent them off, to being able to make me feel better whenever things were going wrong or I was feeling disheartened about my work. I could not imagine I would have made it through this project without you by my side.

Dá fhada an lá, tagann an tráthnóna

Chapter 1 - Introduction

Chapter 1 - Introduction

1.1 Visual scenes and cognition

Visual scenes are complex, defined by their semantically coherent backgrounds or boundaries, prominent large-scale landmarks or features, and often contain a number of smaller local objects (Epstein et al., 2007). The specific spatial location of these objects, alongside the spatial interrelations between objects within the scene, form a coherent and meaningful environment, facilitating the extraction of semantic information and comprehension of the scene. How we derive this information and make sense of a scene is a multifaceted process, where different cognitive systems – such as attention; navigation, decision making; and memory – all play an important role in comprehension (Castelhano, & Krzyś, 2020). For example, when entering a new or novel environment, how we orientate and navigate ourselves around the space, attune to selective aspects of the environment, and create mental representations of the space are all influenced by the semantic information available. Semantic information conveys meaningful content, and aids in the understanding of what is being conveyed, which can become generalised to other contexts with repeated exposure (Proctor & Niemeyer, 2020). In this context of spatial processing, information in and around a space are supplemented with expectations and past knowledge about both a space and the individual objects present in a space, which aid in the processing of a new scene.

The recognition and processing of visual scenes is important for a number of different reasons, making this area of research crucial to a number of different areas in psychology. Scenes inherently convey information, and this information can aid in decision making, (recognising potential dangers, communication, where the context of the scene may require a specific response or social etiquette, and so on) (Gold & Stocker, 2017). However, the processing and recognition of visual scenes goes beyond influencing our behaviour in the moment. Visual scenes play a pivotal role in learning. Due to being a primarily visual species, we observe visual stimulus in the world around us to draw links and create relationships between objects and spaces (Bar, 2004). We can see the importance of scene recognition on learning when we consider the strong focus of visual information on memory formation, in comparison to other modes of information (Rosen et al., 2018). To understand how we process and recognise scenes is to understand how we interact with the world around us.

This project aims to explore memory and scene perception through behavioural means, however, when discussing memory, it is important to acknowledge neuroscientific evidence and how it informs our ideas around how memory systems work and interact with the world. To not discuss the neuroscience aspects of scene perception and memory would be disregarding a large aspect of this research field. And so, while neuroscience will not be tested directly through this thesis, it will be discussed in detail as it guides some of the hypotheses which will be tested behaviourally.

The processing of visual scenes is complex, involving the integration of various visual elements, such as objects, spatial relationships, and contextual cues. For this reason, scene perception goes beyond the physiological constraints of vision to include the phenomenology of seeing (Intraub, 2012). This is to say that a visual scene is not limited to what we see at any given time, but we perceive it as a coherent, continuous and meaningful space. We approach scenes with past experiences and understanding of contextual cues which allows us to be able to make sense of a scene without needing to look at all or even a majority of objects. A quick look at a space, also known as gist, provides enough information to quickly go from observing visual stimulus to processing a scene with meaning and function (Oppermann et al., 2012). This complexity is why conceptualisations of scene perception can range from a reflection of the visual sensory input alone, to a more complex egocentric perspective, influenced by expectations and object-to-context associations. Numerous fMRI studies have looked at the brain areas involved in scene perception, with three cortical regions that showing increased selective activation to visual scenes: parahippocampal place area (PPA), occipital place area (OPA), and the retrosplenial cortex (RSC) (Baumann & Mattingley, 2016; Epstein & Baker, 2019; Steel et al., 2021). These regions have been found to constitute a distinct functional network that interfaces with spatial memory systems. Through this place network we see individual areas having different functions, for example, the OPA is suggested to be important for the processing of scenes that are essential for navigation through the immediate environment (Kamps et al., 2016), while the PPA is thought to be used to identify scenes and landmarks, including local spatial layout, object category, and context (Epstein, 2014), and the RSC uses landmarks and salient objects to anchor the cognitive map (Mitchell et al., 2018). When we look at the complexity of the neural network involved in scene perception, we see that it goes beyond the visual system to understand contextual relevance or the salience of objects.

Memory plays a particularly important role as it is interlinked with many other aspects of scene processing. Memory for a space or similar spaces can inform how we approach and move around a given space, and allow us to approach navigation with efficiency and speed. Semantic memory is a critical aspect of memory which can aid in scene processing. Semantic memory is concerned with storing knowledge, concepts, and meaning, aiding with understanding and use of knowledge (Kumar, 2021). In the context of scene perception, semantic memory allows us to categorise our current environment with scenes we have previously engaged with, which in turn makes navigation and attention allocation more efficient, because there is an expectation and developed schemas of how the environment should be based on what we know from other similar spaces (Intraub, 2012). Closely related to the ideas of semantic memory in scene perception is learning from episodic memory in scene perception. Episodic memory is more so related to individual events, with specificity being a core component, with the capacity to represent a single event, and to locate it in time and space (Baddeley, 2001). In the context of scene perception, episodic and semantic memory are used in similar way, to inform the individual of the space they are exploring, and to provide context of how to navigate the space, even if it is unfamiliar.

Another aspect of memory which is crucial for understanding how we process visual scenes is episodic memory. Where semantic memory involves factual recollection, episodic memory is the ability to recall specific experiences, moments, and events from one's past (Tulving, 1972). Episodic memory is characterised by a subjective sense of time, connection to the self, and consciousness. How we process and engage with visual scenes is strongly influenced by our past experiences and how we have engaged with events in similar scenes. These can guide expectations for how we move around, what aspects of a scene we attune to, and how effectively information is encoded and recalled. A component to how expectations and previous experiences are managed in new visual scenes is through the use of schemas. A schema is a knowledge structure that organises what we know about a given object, person, or event based on prior knowledge. These organisation of these schemas is a crucial part of memory as how stored units of information are accessed determine how that information is used and interpreted (Bobrow & Norman, 1975). These schemas are informed and updated with information from episodic memory, and so, our past experiences have a direct consequence on how we process a visual scene.

However, while this function of memory in scene processing is widely accepted, there is some debate as to the influence of elements of a scene on memory. For example, we are all aware of the idea of walking into a room and forgetting what you went in there for, but what causes this forgetting to occur, and how consistent is this idea of forgetting when crossing over environmental boundaries? Is it an issue of needing a doorway between two distinct rooms, or is it a result of a context shift meaning that the information previously held was context dependent? Some researchers emphasise the influence of the doorway in isolation, claiming crossing environmental boundaries is enough to result in a forgetting effect (Pettijohn & Radvansky, 2016; Radvansky et al., 2010; Radvansky et al., 2011). On the other hand, some researchers argue a doorway alone is not enough to negatively influence memory performance, and that the memory effects of environmental boundaries is a more complex phenomenon (McFadyen et al., 2021; Van Gemert et al., 2024). This example of forgetting is one that is widely experienced, but there are still many questions about this phenomenon, such as the level of information forgotten, the environmental conditions in which forgetting takes place and how to reinstate the information to memory. While these questions have seen some research attention, there is still a lot which remains unclear and in need of more work.

While there has been an increased interest in understanding the role of environmental boundaries on memory performance, Radvansky has been a particularly influential researcher in exploring the memory effects of doorways. Radvansky has conducted several studies which highlight a forgetting effect of doorways, where crossing through a doorway leads to reduced memory performance in comparison to those who do not cross through a doorway. This effect has been explored under the context of probing (Radvansky & Copeland, 2006), contextual shifts (Radvansky et al., 2011), and location updating effects (Pettijohn & Radvansky, 2016). From this line of work, emerged the Event Horizon Model (EHM), which places a strong emphasis on the role for crossing a boundary in memory performance. While this provides a theoretical framework to work with, the model does not provide a satisfactory explanation for some of the previously discussed questions, and so, the need to explore more theoretical ideas is important before approaching the model in detail.

It is not a one-way relationship between scene perception and memory. Aspects of the scene can also have an effect on how we encode a space. Scene congruency, emotional content, and environmental complexity can all be modulating factors on the encoding of a scene. With scene congruency, we see that when objects are congruent with the broader scene

context, it may lead to less detailed encoding when compared to objects with less scene congruency, due to a reduced prediction-error response (Spaak et al., 2022). However, while incongruent objects in a scene may improve recall for the scene, more local object orientated memory can suffer when incongruencies exist within the scene. In a drawing task by Bainbridge et al. (2021), it was found that inconsistent scenes, where additional objects were added that stood out from the scene, while recalled more frequently contained less object detail, and more errors, than congruent scenes. These results highlight how multifaceted scene perception and memory can be, as different components may be simultaneously boosted (global) while others hindered (local) by certain factors (incongruent information).

Meanwhile, emotional arousal, both positive and negative, can increase recollection of emotionally charged objects, as they occupy a privileged position of their neutral counterparts (Buttafuoco et al., 2018). In a study by Buttafuoco et al. (2018), it was found that while emotionally charged objects were recalled more often, fewer objects were recalled from the overall scene. While memory and recall were orientated towards these objects, the efficacy of processing the scene changed depending on the emotional state of the participant.

Finally, scene complexity can result in activation differences for memory passed neural networks. Namely, high complexity scenes (defined by the number of unique objects depicted in the scene) is associated with higher levels of activity in a network of regions including the posterior parahippocampal gyrus (PHG; Chai et al., 2010), the Parahippocampal Place Area (PPA; Aminoff & Tarr, 2015), the Retrosplenial Cortex (RSC; Vann et al., 2009), and the Occipital Place Area (OPA; Dilks et al., 2013). The difference in activation, where high complexity scenes had an increase in activity in comparison to low complexity scenes. Thus, scene complexity can modulate cortical activity in different brain regions, resulting in different levels of memory performance.

All three of these factors demonstrate how the content of the scene the cognitive processes involved in scene perception. The content of a scene can affect our memory, not only because of the layout or presence of boundaries, but also the meaning of the objects and the semantic knowledge we may have about them, and that when in context and out of context, it can affect what we focus on and remember in a visual scene.

While the previously discussed cognitive processes are involved in overall scene perception, there are additional components when we focus on forgetting effects and scene

perception. An example of a component influencing forgetting when moving into a new room includes the categorisation of space (Coello & Delevoye-Turrell, 2007). Categorisation can lead to ambiguities in what we consider to be a scene space. Individual rooms are considered scenes on a different level from a house or building, but each of these spaces could be considered a single scene, or a number of different scenes placed together (Henderson, 2005). Henderson argues that there are some difficulties in defining a scene, due to scene perception being a result of views of an environment from an environment in which an observer is embedded. This issue becomes more complicated when we consider differences between inside and outside spaces. Outside spaces are not categorised as one unified space (Mou, 2025), and yet, there is comparatively little research on environmental boundaries and crossing through different scenes in an outside space. And moving beyond the issue of space, are scenes confined to particular environments, or can a scene consist of a number of environments that are linked through meaning, where it could be a change in task or goal that could be more important in the construction of memory boundaries?

It is when considering these questions about memory in space and scene processing in which the topic of event segmentation becomes important. As we navigate and move through the world, experiencing and carrying out our everyday lives, our senses receive a continuous stream of information, and yet we are able to consistently and decisively segment our experiences spatially and temporally (Zacks & Swallow, 2007). Our ability to segment our experience creates “events” (defined here as discretely conceptualised meaningful activities and periods of time), which help us make sense of the world and categorise the large amount of sensory information we receive at all times (Kurby, & Zacks, 2008). This concept of event segmentation has been applied to spatial memory and scene processing, with Radvansky (2012), highlighting the role of dividing boundaries in our memory for different spaces and the objects therein. For example, the division of environments can mean that the contents of individual rooms could be chunked together, where the objects from an individual room are remembered together or grouped together in memorable units, such as seeing a group of objects on a table (Jafarpour et al., 2022). Also, seeing objects across multiple rooms could interfere with each other, such as seeing a similar model of chair across multiple rooms (Pettijohn et al., 2016).

Considerations of scenes, spaces, and effects on memory have prompted a lot of work, suggesting that the reported effects of scenes on memory are consequential issues that need to

be resolved. As previously stated, memory is interlinked with many other cognitive processes involved in scene processing (attention, navigation, decision making), and yet, there appears to be an element of scenes and environments, such as doorways which can lead to forgetting. If left unexamined, there could be other areas of scene processing which could unknowingly be affected, and so, there is a need to fully understand this process to its fullest.

1.2 What spatial navigation can tell us about event boundaries

When looking at the impact of environmental boundaries and spatial compartmentalisation on the operation of cognitive processes, we can learn a lot from ongoing work in spatial navigation. Spatial navigation is not only the act of moving from a start point to an end point, the concept also encompasses the mental representation and understanding of the space being traversed through. These cognitive representations of a space are crucial for tasks ranging from everyday travel and navigating around a familiar space, to more complex navigational tasks, such as following directions or orienting yourself in an unfamiliar space.

A concept often studied within spatial navigation research is the idea of local versus global processing. This area raises similar questions to those raised earlier with regards to what is considered “a space”. Humans have a strong tendency to form and build local representations, in this case being defined as the current environment/scene being experienced, both when learning a scene and the objects within, as well as learning to navigate through environments (Han & Becker, 2014). For example, if there is an environment made up of several smaller spaces, such as a house or apartment, there is evidence that humans are more readily primed by locations in the same scene than locations which cross scenes (Brockmole & Wang, 2002). This strong tendency towards local processing can be seen when learning routes in an environment, regardless of if learning took place over one or across multiple sessions (Schinazi et al., 2013), as well as in scene learning regardless of whether a scene is divided or presented as one large environment (Meilinger et al., 2016).

A tendency to focus on local elements of a scene could also have a beneficial effect for navigation and orientation. In a pointing task, when provided with local reference frames (corridors), participants would perform better when their body or pointing targets were

aligned with the local reference frame and would often turn their head to align it with the local reference frame (Meilinger et al., 2014). Local reference frames here are defined as surroundings usually visible from a single vantage point, also known as a “vista space”, such as streets or places (Montello, 1993). Global reference frames however are more so a coordinate system which does not rely on local knowledge, for example, cardinal directions (Kuipers, 2000). This strong preference towards local processing was also highlighted by Han and Becker (2014), who found that when participants either learned two neighbourhoods together or separately for a navigation task, strong local representations would be formed regardless of how they were learned. Only when all visible distinctions between neighbourhoods were removed did people behave as if they formed one integrated spatial representation, as demonstrated in changes in the navigational task performance. This finding suggests that the formation of local representations transcended the learning conditions (or temporal differences) between group, suggesting that our local processing is heavily influenced by vista space.

However, when viewing these studies, we should consider the question “what is a space?”. Some of these studies look at how spaces can be integrated together or how vista spaces are developed regardless of whether a space is divided or not. However, the differences between how you move between and look around a large open space in comparison to a number of small, divided spaces are often not considered. Is it satisfactory to state that because we create a local reference frame that we engage with these spaces in the same way? Or would moving between separate rooms a change in scene that we would not experience in a larger open space? With these questions not having clear answers, it is important to look at spaces not only from a local representation standpoint, but also from a global processing perspective.

While there is a large body of work to suggest there is a bias towards local processing, humans can develop strong global spatial maps rapidly. In research by Schinazi et al. (2013), participants were tasked with learning an unfamiliar campus environment over a series of three sessions. Participants would be guided along a route by the experimenter where they were asked to remember four buildings along the route. After the completion of one route they would do the same guiding task with another unfamiliar area of the campus. At the end of each session, they were tested on onsite direction estimates, offsite direction estimates, distance estimates, and the drawing of a sketch map of the campus. After only one session

they performed significantly better than chance both on distance estimation and sketch mapping measures. These results have a significant implication when considering how we process space, being that the participants still performed significantly better than chance when not relying on local representations. This lack of relying on local representations is highlighted by the offsite direction estimates, understanding the relation of the main buildings to the environment outside of the campus, where in this task, local information would not be of use due to the more global demands of the task. This is important to consider when we look at the effect of crossing through environmental boundaries, where local representations may not be accessible anymore, such as crossing into a new room.

This research, and others would imply that the information in multiple scenes can still be integrated together for an efficient spatial map. This concept is supported by Strickrodt et al. (2019), who found that in a pointing task, while locally confined spaces are important in the structuring of spatial memory, that global representations, (features of the space which are present throughout the whole environment, such as a corridor which connects a series of rooms), were also consulted when accessing information beyond regional boundaries, such as in another room. The results of these two experiments show that local and global information can be integrated when needed, and while there is a bias towards local processing during scene perception broadly, global processing is still utilised when it comes to spatial maps and memory.

If we apply these findings to the scenario of moving between environmental boundaries, through multiple rooms, there should not be significant differences between information learned between one or multiple environments due to the importance of global references and the ability to integrate knowledge across spaces. As discussed above, a lot of research in spatial navigation suggests that humans are able to develop a local reference frame which can be adapted and changed, and is not necessarily influenced by whether a space is subdivided or not. In instances where a local reference frame is not available, global components of the space still provide information and can help orientate and make sense of a space. While behaviours may differ between interacting with the spaces or how we approach the learning may be different, in terms of recall and memory for a scene, the discrepancy in differences between the availability of local and global information on memory has not been fully explored.

Before discussing the current leading model around crossing through environmental boundaries and memory, it should be highlighted that there is a strong neuroscience basis for the effects of crossing through environmental boundaries on cognitive processes. Work has been conducted understanding the role of hippocampus, with research looking at the neural firing patterns of place cells. Place cells are a type of neuron in the hippocampus that fires when animals enter a particular space in its environment. Some results in place cell research have argued that remapping was found when there were geometric and contextual changes in environments, with doorways playing a privileged role in segmenting the neural representation of space (Spiers et al., 2015). Similarly, general patterns of specific neural codes have been found within the hippocampus. When participants successfully distinguished environments from each other, each distinct environment resulted in distinct neural codes from one another (Kyle et al., 2015). These hippocampal studies results suggest that pattern separation/ environmental segmentation mechanisms play an important role in how we successfully retrieve memories.

However, this work is not only localised to neural activity within the hippocampus, because the neural firing of grid cells within the Entorhinal cortex has also been examined in relation to environmental boundaries. Grid cells, which are proposed to support path-integration-based navigation, in this region produce more error related spikes in firing in navigating the further participants travel without encountering a boundary (Hardcastle et al., 2015). In this experiment, it was found that the spikes in firing rates were demonstrating a drift in the grid pattern when there was an absence of input from environmental boundaries. Furthermore, the same study also found that interacting with a boundary would result in direction correction, as finding a northern boundary would inform the north-south axis directionality, demonstrating the importance of boundaries to our navigation. This positive effect of boundaries on navigational ability is highlighted when we consider that place and grid cell representations interact to support accurate coding of large-scale spaces (Bush et al., 2014). This association is to be expected, as previously stated, there is a lot of interaction between navigation systems; however, it is important to note the benefit of boundaries for reorientation and navigation, which seemingly memory would also see benefit from.

It is clear then, from the spatial navigation research literature that boundaries affect cognitive processes, both in terms of global and local processing, and how we use local referencing and global information to orientate ourselves in a space and navigate around a

scene. There is also a neural component to the role of boundaries in spatial navigation, both with the remapping of place cells and the firing of grid cells. By contrast, the memory research literature yields a contrasting set of predictions, and results.

1.3 What is event segmentation?

Event segmentation is a cognitive process by which we break up information into discrete events. We use this process to make sense of and organise the volume of stimulus we experience and perceive from the outside world. Event segmentation occurs, and has been studied, in a wide range of contexts. For example, research exists regarding the ways in which we segment a narrative text (Feller et al., 2019), a series of actions (Levine et al., 2017), and visual scenes (Swallow et al. 2018). The nature of what is constituted as a boundary depends on the medium of the information being segmented, for example, text may be segmented through paragraphs, while a movie may be segmented through a change of scene. Segmenting is thought to aid memory and learning (Gold et al., 2017): through the chunking together of information, a sequence of events or a number of objects can be recalled better when a part of a distinct event. However, the length of the event itself can influence what kind of information is better retained (Logie & Donaldson, 2021). Participants recall fine grain details and individual components of an event better when events are shorter and more numerous. In contrast, participants recall more details about narrative and semantic information about an event better when events are longer and fewer.

Research began exploring event segmentation in the seminal work of Zacks and Tversky (2001), which introduced the Event Segmentation Theory. This theory was developed to understand how people perceive routine events as these events unfold in time. The theory emphasised the role of perceptual cues and contextual information in shaping event boundaries, utilising partonomic hierarchies. A partonomic hierarchy is traditionally used to characterise objects, where the focus is on the subparts that make up a whole. This can also be applied to events, looking at the routine or individual actions which make up a behaviour in an event. Goals and routine were identified to have an important role in event segmentation. Routines were seen as behavioural templates with specific goals, and a series of routines constituted large events, such as making a cup of coffee being seen as part of a morning routine, as opposed to more idiosyncratic acts, which were seen as individual events, albeit much smaller, such as smoking a cigarette being made up of putting it in your mouth,

breathing in, taking it out etc (Keren et al., 2010). It was believed that unexpected stimulus, an event that would not allow us to continue our routine, (i.e., a bus that does not arrive) that would break a pattern would result in event boundaries because they were no longer a continuous activity (Reynolds et al., 2007). Attention becomes guided by the structure of recognisable events and so, an unpredicted event disrupts the sequencing of events (Hard et al., 2019).

While these ideas around goal and routine defined the early development of the Event Segmentation Theory, it quickly grew beyond the ideas of routine. We have to engage with unfamiliar spaces and carry out new behaviours depending on the context, and yet we are still capable of segmenting these sequences appropriately, regardless of surprise or expected outcome (Hansen et al., 2021). Thus, researchers began to look at the consensus as to *when* segments take place.

As event segmentation is an automatic and often unconscious process, we do not get to choose when a segmentation takes place. For example, in a study by Levine et al. (2017), where participants, who were either figure skaters or had no experience with skating, were asked to segment a figure skating routine, there was a significant consensus between both groups on where the event boundaries in the routine were and when a new section began. Similarly, children, despite their relatively reduced life experience, provide similar (albeit ‘noisier’) boundaries to adults when looking at the same information (Zheng et al., 2020). There is evidence to suggest that perception of multisensory event sequences and their structures occurs early in development. Lewkowicz, (2008), showed that infants as young as 3 months old perceived the order of 3-element sequences. From these sets of results, we can see that segmenting events appears to be a cognitive process that is developed at a very young age and only becomes more refined with age. To this point of event segmentation as an automatic process, some research reports that multiple streams of segmentation can co-occur at the same time, with the captured/represented events ranging from as short as a few seconds, to minutes at a time, depending on the information available at the time of segmenting (Sargent et al., 2013). The idea of co-occurring events is important to consider when we look at the variability of segmentation timescale variations, from short and fine grained to larger more course segments (Sasmita & Swallow, 2023). An example of this would be when watching a movie: a given scene may be occupying one event stream, meanwhile the actions of the characters may be occupying a separate event stream. Both

segments are co-occurring, however the size of the segments and the level of change to define the events vary widely. Despite the complexities of numerous concurrent streams of information, where each stream is not made up of equivalent information, and so demand different levels of cognitive processing, event segmentation can parse out information and categorise it into discrete events to be remembered and recalled easily and efficiently.

The prefrontal cortex (PFC) has also been strongly associated with event segmentation. The PFC is thought to be crucial for goal-directed behaviour and organising everyday life routines (Krueger, & Grafman, 2008). The viewing of event boundaries is reliably associated with state boundaries in the medial PFC (Geerligs et al., 2021). Similarly, a study using intracranial EEG recordings reported high frequency activity (50-150Hz) in the hippocampus and dorsolateral PFC tracks event saliency (Jafarpour et al., 2019). Furthermore, those with lesions to the ventromedial PFC had impairments on event segmentation, namely selectively impaired coarse segmentation (Zacks et al., 2016).

A number of fMRI studies have also identified the involvement of the hippocampus and the PFC in the detection and formation of event boundaries, providing a neural substrate for event segmentation, (Clewett et al., 2019; Griffiths, & Fuentemilla, 2019; Liu et al., 2022). Thus, there seems to be consistency in the brain areas involved in the process of event segmentation, suggesting the existence of a neural network explicit to the segmentation of visual scenes. This network is made up of areas associated with memory and visual perception, such as the role of the PFC and hippocampus working in tandem with the activation patterns observed by Yates et al. (2022). Our brains are equipped with these complex networks from a very young age that allows us to distinguish the order and boundaries of a sequence, however, this network appears to become more refined and complex as we get older, as suggested by the reported differences in children's and adults' segmenting abilities (Zheng et al., 2020).

The question of when segmentation takes place becomes more complicated when we are looking at real life experiences or a series of actions, where there are not explicit divides that we would find in text or film. Swallow et al. (2018), measured when participants segmented a video of actors carrying out everyday activities, such as doing laundry, that was presented to them from a first- and third-person perspective. They found that segments were relatively consistent, whether in first or third person. However, as it was still participants

watching a screen, we cannot be sure that these consistencies would also be found when carrying out the behaviours themselves.

This concern over defining event segmentation has led some people to take different approaches when segmenting human behaviour. Some consider goals or tasks to be the events, such as completing chores or travelling to a new location (Boggia, & Ristic, 2015), and once they are completed, a new event begins. Others consider this process to be more spatial in nature, with environmental boundaries acting as the beginning and end of events (Brunec et al., 2018), so moving through a boundary, say a doorway, is where event segmentation occurs. This latter perspective has led to the formulation of the Event Horizon Model (Radvansky, 2012). This model suggests the spatial transition from one event to the other can have a beneficial or detrimental effect on memory, depending on a number of different factors.

1.4 The Event Horizon Model

The Event Horizon Model (EHM) of memory and navigation (Radvansky, 2012) was formulated to provide an account of how the transition from one event to another can have a detrimental or beneficial effect on memory performance. It is suggested that the consequences of moving between events being dependent on the nature of the information. For example, when we move into a new environment (e.g., open a door and walk into a new room) we typically encounter a large amount of new information. The cognitive load associated with encoding this information is hypothesised to increase the difficulty of recalling information accurately and efficiently at the point of moving between events (cf. staying within an event). In line with this prediction, studies have reported that, participants struggle to remember in what order objects were presented when there was a context shift (e.g., a move into another room) vs no context shift (Radvansky et al., 2015). These results suggest that when trying to recall object order, segmenting events has a detrimental effect on memory performance. This effect is observed when tested both in the later environment, and when returning to the first. Thus, these observed differences were not the result of context dependent recall, but were rather tied selectively to the experience of crossing through the environmental boundaries (DuBrow & Davachi, 2013; Lawrence & Peterson, 2016). However, if participants go to a third room, memory performance is worse than if they had returned to the first room. In both cases there are two spatial event boundaries, and so, the

deterioration of memory performance is suggesting some retrieval interference (Radvansky & Zacks, 2017).

Critically, others have reported that the increase in processing activity associated with encountering environmental boundaries lead to *superior* memory. For example, when learning objects with a context shift, there were no significant influence of doorways on forgetting when participants were asked to identify items recently encountered across multiple spaces (McFadyen et al., 2021). An explanation for this finding is that we experience an “event boundary advantage” (Pradhan & Kumar, 2022). This advantage is where there is an observed improvement in memory for information at the boundary of an event than in other portions of the event. This is attributed to prediction error related enhancement and the expectation of updating the currently held memory model to a new event, as a method of consolidation. Pradhan and Kumar (2022) found attention to be a mediating factor into the extent of the effect seen for information at boundaries in comparison to other portions of the event.

At first glance these two conflicting findings associated with boundary-related recall (i.e., impairment vs enhancement) are puzzling, but the EHM argues that the cognitive consequences of event segmentation are dependent on 5 principles (Radvansky, 2012).

- a) “The segmentation of streams of activity into event units”, meaning when event boundaries are identified (e.g., walking into a new room) we segregate the information within the event into a discrete event model to be stored in memory.
- b) “The superior availability of information in the working event model”, where information in the current event has a privileged status of being more available for recall, as a reflection of the structure of the current event.
- c) “The construction of a causal network that can influence retrieval”, meaning that people can draw semantic links and derive temporal sequences for their memories. On top of tying memories together leading to associations in recall, information that is causally connected to other memories is also seen to be more important and better remembered, which highlights the importance of meaning and context in recall and forgetting.
- d) “The superiority of memory for information stored across multiple events in *non-competitive* retrieval”. This principle is in relation to the segregation of

different information into multiple event models, which serves to organize the information available to encode, thus improving memory. For example, if you were trying to remember objects unique to a kitchen and living room at the same time.

- e) “The occurrence of retrieval interference for information stored across multiple events in *competitive* event retrieval”. This final principle is in relation to the parsing of information, and the selection of a specific event model when the information needed exists in several. For example, if you were trying to remember where you last used your credit card, but you used it in a series of shops in succession.

In isolation, these principles offer some ideas about how event boundaries can influence memory. Yet in practice there are no established conditions (i.e., event model hierarchy) that determines when some principles overwrite others. For example, the EHM has been criticised for the extent to which it fails to acknowledge the extent to which event units (suggested to be consolidated and stored discretely, *Principle A*) can also activate adjacent memories when cued (Ezzyat & Davachi, 2011). This idea has received some attention in later work, for example, Zacks (2020), makes an argument for the interconnectedness of events. Zacks discusses the “working event model” where events are held as both perceptual representations of an unfolding event, and a working memory representation maintaining information through an event. Within this working event model, participants can draw on previous knowledge to aid in event comprehension.

On the other hand, the idea posited through *Principle E* suggests information has strong associations that does make it difficult to retrieve information that may be present in multiple event units. Along the same lines, the idea expressed in *Principle C* suggests the causal network of events can lead to the establishment of a temporal sequence, meanwhile *Principle E* suggests that the information interlinked in multiple events makes it more difficult to establish a temporal sequence. Further work has supported these ideas both being present when presented with information at and across event boundaries. Clewett & Davachi (2017), examined the neural mechanisms of event memory, and found that temporal memory was superior when experienced within a context, and hippocampal activation patterns were more similar for encoding and recall within a context than across a context. Through this example, we see how information across multiple contexts results in a reduced temporal

memory, supporting the idea of *Principle E*. However, within the same paper, they argue that memory integration occurs at event boundaries, where increased hippocampal activity at event transitions correlates with successful serial recall across those transitions, thus supporting the causal network of *Principle C*. Where the issue is here is the lack of clarity in when we should expect one outcome over the other. As a result, the EHM would benefit from establishing a hierarchy, or conditions in which principles take priority over one another. While research has clarified how these principles may work together, making a decisive prediction on memory performance as the model is currently structured is difficult. Including some clarifications on how the components of the model interact with each other in complex situations would be beneficial to the predictive power of the model.

While some ambiguity is expected in a model exploring processes which take place in complex scenarios such as real-world environments, our understanding of scene processing and perception would be improved by establishing the relationship between the principles and the conditions wherein some principles override the others. Wang et al. (2023), provides some clarifications which would be invaluable to incorporate into the EHM for clarity. One clarification they make is between information close to event boundaries and information further away. With this clarification they identify enhanced memory for information presented at boundaries while arguing for impaired temporal order memory accuracy across a boundary. Expanding on some of the ideas within the EHM as Wang et al. do would help with the predictive power of the model. Similarly, they acknowledge that there are different types of event boundary that may result in different behavioural outcomes. The first type is an external change, where there is a visual or auditory contextual shift, such as walking into a new room, in which external changes enforce a change on an individual's internal event schemas. The second type is an internal change, such as a shift in attention or a change of goal, and these can occur independently of external changes. In such instances, changes in internal states lead to, rather than result from, breaks in the causal connectivity between events, which is an essential element in event memory. These types of event boundaries are an important distinction to make as an event boundary is not a unitary concept, and the EHM would benefit from making this categorisation explicitly clear within its model.

The evidence base surrounding the model is mixed. The findings of some studies arguably support the model (Pettijohn & Radvansky, 2016) and others do not (McFadyen et al., 2021). The current model having a lack of clarification in the interactions between

principles leads to an issue where the model is not being refined or altered as new research is being conducted. A model of this complexity, exploring multifaceted scenarios such as memory in real world environments, can result in a lack of predictive ability, due to a lack of internal relationships in its components allowing for several interpretations. With a model such as the EHM, falsification is important, however, the EHM in its current state, struggles with falsification due to being able to explain all outcomes. Villarreal et al. (2023), emphasise how falsification is an important limitation to impose on complex models, as it leads to the refinement of ideas, the development of new measures, and a stronger body of support through empirical research. The EHM is an example of a model which is in need of refinement and more consideration of the importance of falsification. It is difficult to develop and improve upon a model which does not allow itself to be proven wrong by making concrete predictions. Due to this lack of predictive power, it is difficult to push our knowledge further surrounding event segmentation, as this model is difficult to challenge and improve.

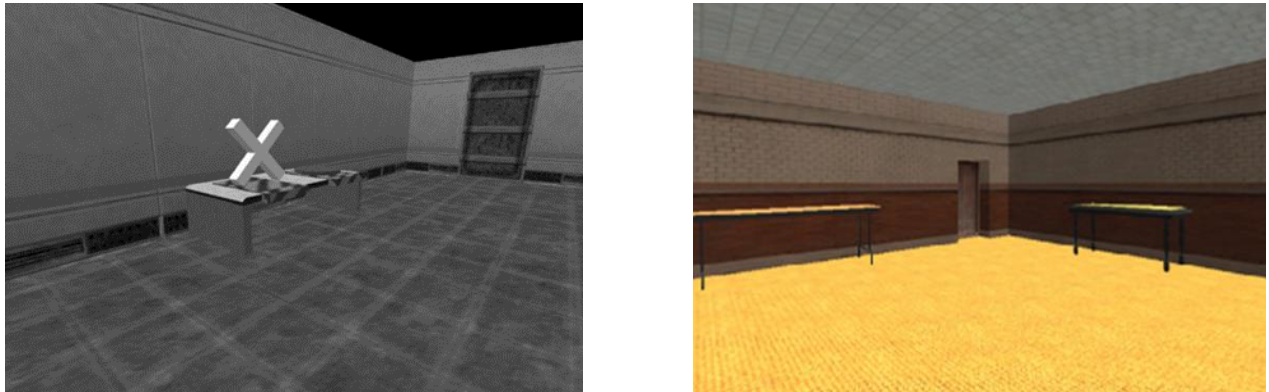
1.5 The Event Horizon Model: Are doorways a benefit or detriment to memory?

A large portion of recent research has produced evidence highlighting the detrimental effects of event segmentation on memory (Lawrence, & Peterson, 2016; Ongchoco, & Scholl, 2019; Pettijohn, & Radvansky, 2016). There has been comparatively less evidence for the benefits of event segmentation on memory performance, despite the EHM suggesting both positive and negative effects on memory performance are possible. Studies that focus on participants recall ability for objects across multiple rooms versus presented in the same room consistently report that moving across event boundaries leads to forgetting (Horner et al., 2016; Pettijohn, & Radvansky, 2018; Radvansky & Copeland, 2006) (Figure 1.1). This research often involved using Virtual Reality to generate environments, often empty rooms, where objects or lists of words are presented in a sequence, with the difference between conditions being whether the list of stimuli was learnt in one room or across multiple. The findings for these studies often rely on *Principle E* of the EHM to explain their results, where information held across multiple events results in competitive event retrieval, and thus impaired recall ability. Radvansky and Copeland (2006), found participants recalled a sequence of objects with less accuracy when there was a contextual shift. suggest multiple

cognitive representations of objects result in their misplacement or forgetting of where they placed in a sequence.

Figure 1.1

Examples of VR Environments used in Event Segmentation Research



Note. On left: Radvansky & Copeland (2006), On right: Horner et al. (2016).

Research suggesting doorways lead to forgetting often present two accounts of this outcome. The first is that the act of passing through a doorway may create a mental boundary that interferes with the continuity of memory, thus, leading to forgetting or delays in recalling information. The second is that moving through doorways results in an attentional shift from one environment to another, and this shift can lead to an increase in cognitive load. As a result of this increased cognitive load, we may need some time to orientate to the new space in order to return to a baseline cognitive demand when processing a space and its contents. However, this work is not the only to observe these cognitive factors, as Wang et al. (2023), found that not only does passing through a doorway cause memory impairment, but so too does the anticipation of passing through a doorway. These results highlight when the brain anticipates the crossing of a boundary, it may experience side effects, such as memory impairment, before even crossing the boundary. These findings imply that the complexities of scene processing are not limited to the act of crossing a boundary, but other cognitive processes, such as anticipation and prediction, can result in the memory effects of event boundaries occurring before we encounter the boundary itself.

An alternative body of research, though comparatively smaller, found some results suggesting the benefits of event segmentation on memory performance, focusing more so on *Principles B* (superiority of current event memory) and *C* (causal network formation) of the EHM. These findings would explain results by emphasising the role of event segmentation in chunking memory, and how chunking can make recall easier (McFadyen et al., 2021; McGatlin et al., 2018). However, the process behind grouping spatial information and experiences require further explanation. Shin and DuBrow, (2020), argue that experiences are grouped together according to what is inferred to have generated them, and this can occur independent of perceptual change and when transitions are predictable. It would follow then, how people recall chunks may appear as though some forgetting or superior retrieval has taken place, where it more so may be a case of variation in how the information was coded. This is an important point to consider as event segmentation theory was not developed with spatial boundaries in mind. Event segmentation was initially concerned with routine and behaviour, and so, while we are looking at crossing a doorway as the event boundary, the experience of carrying out an experiment could act as a singular event due to the novelty and process of being a participant. Alternatively, the participants may perceive more event boundaries or segments beyond the established doorway in the experiment.

Alternatively, while the detriment on memory have been noted, an Event Boundary Advantage (EBA) has also been studied where there is better memory for information at an event boundary compared to other portions of the event (Pradhan & Kumar, 2022). While Wang et al. (2023) suggested the role of cognitive load and mental barriers to encoding, where anticipation of a boundary can effect recall performance, EBA suggests attentional shift at boundaries result in better memory performance.

While research suggests that some cognitive components, such as attention, are aided by the event boundaries, whether it be the organisation of space, or change in context. However, given that we cannot concretely determine whether doorways are in fact acting as the event boundary, it is difficult to make a claim on their effect on memory. It remains unclear if the doorways in these experiments are the only segmentations of the space being made, or whether an experiment is too novel of an experience to not register as a single event in itself.

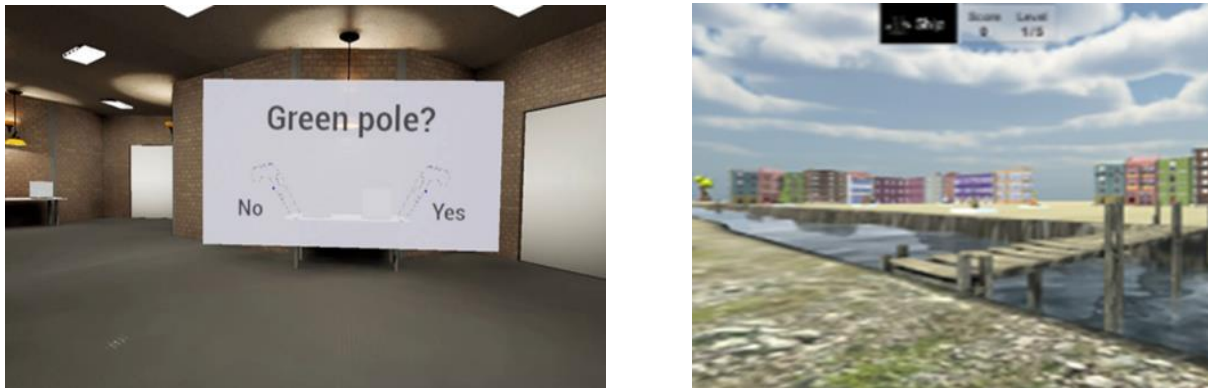
Some of the variations in findings could be explained by ideas such as context dependent memory (Godden & Baddeley, 1975), where participants are better are recalling

information in spaces similar to the spaces in which they learned the stimulus. This would explain some of these findings, such as memory performance being better when recalled in the learning room, or contextual shifts resulting in poorer recall performance. However, context dependent memory does not explain other aspects of these findings, such as differences in memory occurring when the rooms being moved between look so similar to the learning space, or how the anticipation of approaching a doorway can affect memory performance. While context dependent memory can inform some of the ideas being discussed, it is not holistic enough to encompass the wide range of findings being discussed with regards to event segmentation.

Taken together, it remains unclear when event segmentation can result in positive or negative outcomes for memory. What then, determines when these effects generate positive and negative effects? Without a clear definition of competitive stimulus or what it means to see “similar objects” across multiple events, it is difficult to make a strong prediction. In terms of the design of the empirical studies, we can see that when focusing on a doorway in a simplistic environment, without a focus on real world situations, a negative effect is produced (Pettijohn, & Radvansky, 2016a, 2016b, 2018), however, when there are more complex environments or tasks being presented, a more positive effect is produced (McFadyen et al., 2021; Peer, & Epstein, 2021) (Figure 1.2). These positive findings suggest that in event segmentation research, more consideration should be given to ensuring the results are ecologically valid, and that experimental design is representative of real-world complexities.

Figure 1.2

Examples of Complex Environments used in Event Segmentation Research



Note. On left: McFadyen et al. (2021). On right: Peer & Epstein (2021).

Critically, the theory itself is relatively unclear regarding its predictions. As previously stated, there is room within the theory to include a mediating component taking account of semantic importance of the stimulus, or how attention is being allocated within a scene. With additions to the model, our ability to predict the outcomes of event segmentation on memory performance would be improved. With stronger predictive power, we are able to refine and develop our understanding of event segmentation through research more rapidly than currently being achieved. As these findings are being explained through the act of crossing through a doorway, there is a chance that the wrong conclusions are being drawn from valid studies due to a lack of clarity in the model. For example, attention in an empty room learning a list of words will be entirely focused on the task stimulus, and so segmenting that event may not be seen as breaking up an experience, but more so disrupting learning. Moreover, if we have a real-life environment that participants are able to explore freely and interact with, their attention is much more divided, and taking in a lot more stimulus, thus segmentation would be necessary to make sense of that large volume of information, to chunk stimulus together. While the established principles could explain these two situations in isolation, they do not clearly explain how a difference in memory performance exists between them.

When we are studying this topic, we cannot look at the memory process in isolation, or ignore the context in which these tasks are being carried out in. As previously discussed,

memory, attention, and navigation are all interlinked, both on a behavioural and brain activity level, with regards to spatial navigation and scene processing.

1.6 Theory in practice: concerns around real life application

It is not within the EHM alone that there is scope to improve clarity in this domain. Part of the issue regarding predictions associated with the theory comes from a lack of clarity/agreement regarding the nature of event boundaries within this literature. With this issue of what is considered to be an event boundary, methodological inconsistencies emerge as a result, which could possibly explain the difference in findings among different studies. There is some affirmation in previously mentioned research that it is the act of walking through a doorway that leads to the difference in memory performance. However, event segmentation is not space specific. As previously mentioned, event segmentation is not unique to spatial navigation or scene processing, as we also see it in written text and narrative. However, within spatial navigation, the boundaries in question can be temporal (van de Ven et al., 2022) or goal orientated (Magliano et al., 2014) and it remains possible that the boundaries in question might not be those predicted by the experimenters. For instance, participants may go through a doorway because of a new goal. This raises a concern about using experiments as a whole because this novel experience with a single unified goal and a series of actions may register as a single event.

Even when the experiment is looking only at spatial boundaries, such as doorways, there is no consensus into what qualities are needed for something to be considered a boundary where the event will be segmented. In a study by Negen et al. (2020), it was found that responses in both navigation and pointing tasks changed only as a function of *looking* like a boundary (looking like a wall), as opposed to acting like a boundary (being a physical barrier hindering movement) suggesting that variations in spatial coding are more closely linked to the visual properties of environmental layouts than to whether they contain physical boundaries. While the EHM does not specify what is meant by an event boundary, and so none of these results inherently contradict any of the ideas proposed by the model, these findings do prompt questions as to what this model considers to be a boundary. Would a physical boundary segment an event, or does there need to be a visual cue? Defining what is considered a dividing boundary would be in service of the EHM, as it would establish clearer conditions under which we would observe the memory effects of event segmentation (Brunec

et al., 2018). Looking at the ongoing research exploring what can constitute an event barrier or not, it would be beneficial for there to be some refining of the model to include some clarity or include some consideration of differences between spatial/temporal/physical boundaries.

Aspects of the methodology in empirical work to date are also contributing to this mixed theoretical picture. Most work has utilised virtual reality when investigating the effects of event segmentation. These studies make the claim that because they are placing participants in interactable environments, they are experiencing highly similar to real life situations and so the results of their studies are representative of the concepts of event segmentation (van Helvoort et al., 2020). However, most of these studies feature participants being effectively ‘teleported’ from one identical large empty room to the another (Horner et al., 2016; Logie & Donaldson, 2021; Radvansky & Copeland, 2006) This experience is not well aligned with the dynamic environments that participants may encounter in real life, for example, these environments do not utilise different types of rooms or spaces, or different sizes, or even different boundary types. If there were to be more variation in the rooms, it is possible we would see less of a detrimental effect, because different spaces would be less competitive for memory. A future research paradigm could include an exploration of an attentional shift from say an office to a kitchen. The representation of boundaries in research has not been explored, being represented as a doorway with no door, where it may be interesting to look at open plan spaces, or spaces without doorways, such as an outdoor environment. Outdoor environments can be segmented and perceived as distinct events, and doorways are not a part of outdoor segmentation.

Aspects of memory being probed might also influence outcomes. Event segmentation as a concept was developed to explain how humans naturally make sense of a continuous stream of information, and how we segment our conscious experience into accessible events. Yet, studies probing the construct only involve a context shift while participants carry a highly artificial memory test. For example, participants have been asked to, somewhat artificially, learn a list of words (Jafarpour et al., 2022), or recall a sequentially presented set list of objects in the correct order (Sols et al., 2017). It could be argued that such work cannot support or inform interpretation of a model intended to be as all-encompassing as the EHM.

There is a risk associated with generalising very specific results to our more complex everyday experience. Our understanding of not only how we segment the world into discrete

events, but also what segmenting our experience means for memory, will benefit from going beyond rote memory and sequential recall. This highly controlled approach is useful for isolating and highlighting how some cognitions work and exist, but evaluations of a theory designed to account for cognition in the real world will benefit from a change in experimental approach.

While some of these concerns may be perceived as being focused on methodology used, there is an aspect of scene perception being overlooked in these methodological issues. There is an inherent proprioceptive component to memory in spatial cognition. We can see this with the use of turning through a journey to break up an environment in recall (Brunec et al., 2020), as well as proximity to a boundary producing changes in memory (Hardcastle et al., 2015). When navigating a space, we are aware of our place in that environment and because of this proprioceptive component, VR is one of the most authentic methods of analysing the topic of event segmentation. For appropriate responses, it is important for the participants to be able to walk around a space, to physically move their body around an environment and through a boundary, an experience we cannot achieve with a computer and screen (van Helvoort et al., 2020). Current research is aware of this, hence why there is a large focus on using VR to explore event segmentation. However, challenges implementing the technology appropriately, whether it is through teleporting or using identical environments, are restricting research and preventing it from moving forward in new and exciting ways. As a result of this implementation issue, it is worth looking at how VR is being effectively utilised in other areas of psychology.

1.7 Learning from other Virtual Reality studies

While there is a small but growing number of researchers that use VR in theoretical psychological work, it has a longer history of being used in more applied research. Namely, interventions and therapy programs have been utilising VR for around 20 years and has seen great success in rehabilitation for stroke victims (Laver et al., 2018), and enhancing education learning (Mazhar & Al Rifaae, 2023), among many other areas. However, the two disciplines which we have seen VR effectively used to its fullest capabilities are within autism and phobia research. There is a large body of work looking at how to use VR (Turner & Casey, 2014; Vasser & Aru, 2020), how to make it accessible (Tabbaa et al., 2021), and how to tailor it to the needs of the research topic (Cullen et al., 2021; Pan & Hamilton, 2018), and social

skills training in autism and exposure therapy research in phobias are the basis for a lot of this work.

Autism research has effectively used VR in social skills training. Here, real life social situations are recreated with the aim of giving the experience of and learning about a scenario in a safe controllable space. This is important for those with autism due to the stressors and unpredictability which may arise from carrying out some of these interventions in the real world. VR allows for a tailored experience which matches the needs of the participant. Examples include job interviews (Smith et al., 2014), or ordering food in a restaurant (Moon & Ke, 2021), where there is scope for experimenters/clinicians to have a large amount of control on the number of people, number of responses etc. Results from these studies confirm the effectiveness of using VR in comparison to more traditional methods, such as social stories and exposure therapy, where consistently VR methods would show improvements over real-life counterparts (Bellani et al., 2011).

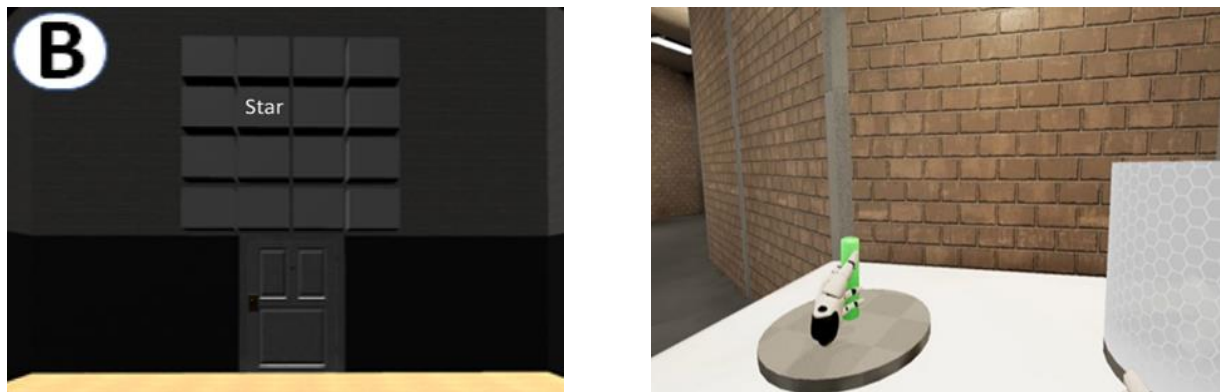
The focus of this approach is to create a real-life experience but having a level of control we could not have in the real world. In the restaurant example, depending on the confidence of the participants, there could be more free seats to choose from, or only seats on partially full tables etc, and with each trial, these variables could change depending on the needs and performance of the participant. In this example, we can see VR being used as an exploration and recreation of the real world, where the elements needed to produce a real-life experience are present, but the factors affecting the study are highly controlled and can be changed. To apply this to event segmentation, it would be creating a large, single environment for participants to explore, then for the next trial asking them to explore a similar environment, but this time it is broken up with a number of doorways/boundaries.

While therapeutic interventions for social skills training are different scenarios from assessing and measuring memory performance, event segmentation research has benefited from testing in more ecologically valid conditions using VR. Findings suggesting an alternative effect of event segmentation on memory performance, as opposed to the forgetting effects widely reported, are often carried out using dynamic virtual environments that allow participants to explore with complex stimulus to learn (e.g., a room with multiple objects to pick up and interact with) rather than more arbitrary stimuli (e.g., lists of words, or basic objects) (Figure 1.3). When memory studies are carried out in complex, intractable environments they show mixed evidence for the effects of event segmentation on memory

performance, (McFadyen et al., 2021). In studies carried out in complex environments which support event segmentation causing forgetting, other factors were found to have a bigger influence, such as the distance walked between objects (van Helvoort et al., 2020).

Figure 1.3

Comparing Stimulus to Learn in Different Experiments



Note. On the left is an example of an environment utilising a list of words in an empty space (Logie & Donaldson, 2021), on the right is an example of an environment with objects that can be picked up and moved by participants (McFadyen et al, 2021).

This inconsistency of findings across the two different experimental approaches, (whether there is a priority to accurately represent environmental complexities or not) highlights the potential value of testing theories under ecologically valid conditions. While reductive experimental paradigms can provide insights into how specific variables operate, it is critical to then expand these variables to see if they can be observed in more realistic situations. The utility and validity of a theory come into question if its components can only be seen in more abstract and removed scenarios. This is not to say that the theory is incorrect, but more so that our understanding may be skewed by the previous reductionist work. We can see this with the EHM, where the principles in isolation make sense, but under a real-life scenario, such as using your credit card across multiple shops, we see multiple principles of the theory becoming involved in the ability to recall, and the model cannot offer a satisfying answer to how memory may work in that scenario. This example is why once a theory is established, we need to look towards testing its components under ecologically valid

scenarios, to find and confront any issues that arise, but also to ensure the theory is offering an insight into our cognitive processes in real world experiences.

We propose researchers interested in real-world perception generally, and event segmentation specifically, benefit from providing participants with engaging virtual environments that ensure the feeling of a real-world interaction and the sense of self experiencing a scenario. Studies in autism (Wallace et al., 2017) and phobia research (Costa et al., 2018; Ling et al., 2014) focus on creating environments that generate a self of presence, and ensuring the participant feels like they are actually engaging with a real-life experience. If we look at the previously discussed issues around methodology in event segmentation research, there is a focus on testing a theory, and less so on trying to apply it to a real-life scenario.

This consideration for presence and accessibility need not compromise the manipulation of variables or test conditions. For example, we can manipulate the number of people or the number of speaking responses in a social situation in social skills training, while still retaining the social aspect of the scenario. So why, when we are studying spatial cognition and event memory in everyday scenarios should we study them in more abstract concepts and make it so we are not looking at a real-world situation, but more so a rote memory test in a basic virtual environment? If we wish to understand how we interact with the real world, we need to ensure our experiments are representative of the real world.

1.8 Aims and Objectives

Based on the previous sections discussed in this introduction, there are 3 main aims of this research project. The first is to assess the ecological validity of past findings supporting the event horizon model. The second is to investigate under what conditions do we see differences in memory performance. The final aim is to highlight the utility of VR in psychological research.

1.8.1 Ecological Validity and the Event Horizon Model

In order to look at the first aim of ecological validity, it was important to try and reproduce the findings from some of the work of Radvansky in his series of “Walking

through doorways causes forgetting” studies (Pettijohn & Radvansky, 2016, 2018). I created environments where there was either a doorway present or not and looking at the memory performance after the exploration period. However, there were some alterations in order to make the tests more ecologically valid. First, the studies were explorable scenes, for example, an office space, filled with objects that had meaning. In comparison to previous studies, where participants would be learning a series of words or objects presented in empty rooms, this approach attempted to place the participants in an environment they could possibly see in the real world. This approach also acknowledges that objects have meaning in spaces, that some objects would naturally be closer together or used in tandem, thus these spatial relationships may be relevant for the participants encoding of the space.

In this attempt to be more ecologically valid, it was also important that to recognise the multifaceted nature of memory, and so there were two measures of memory performance, being free recall and forced choice recognition. This approach was taken to look at what level the scene processing was taking place, whether participants could remember seeing objects in isolation or without its context, or whether they could remember the objects place in the scene and what form it took. This was deemed to be important to understand whether participants were learning a list of names for objects they were seeing, or whether they were learning the scene with objects in it.

1.8.2 When do we Find Differences in Memory Performance

The second aim is closely linked to the issue of falsifiable models previously discussed. There is a mixed evidence base for the effects of segmentation on memory, and the model would benefit from establishing a hierarchy for the models’ principles to aid in the predictive power of the model. This was done through a series of follow-up studies, that utilised the same experimental design, however, the environments would take different forms depending on what factor we were focusing on. For example, when looking at the role of aesthetic differences between spaces, we had the performance of two similar rooms contrasted with performance in two aesthetically different rooms, where objects were matched across scenes. Similarly, if when focusing on the transition period between spaces, we had some participants explore two rooms with an open doorway between them and compare their memory performance to those exploring two rooms with a short corridor between the rooms. The reason behind these choices was to think more about the spaces and

for what reason do we divide spaces. And to do this, we need to present the spaces we are testing in as environments with functions, that have a purpose and that the participant may bring prior knowledge into to help manoeuvre around the space. By emphasising components like the transition period between spaces or the function of the space, we could create a clearer image of what it is about transitioning event boundaries that affect memory, is it the spaces or the transitions themselves, and what is it about the spaces or transitions that need to be altered to see these effects, while being able to confirm what factors do not have an effect.

1.8.3 Utility of VR in Psychological Research

The final aim is much more practically orientated, showing how VR is more than just a gimmick or flash in the pan fad, and how psychological research can benefit from its utility. VR was utilised throughout every study in the project, including one study that was carried out online, where VR was used to generate a naturalistic walkthrough of an environment which was recorded to show participants. The simplest function that having VR allowed us to carry out was having several environments with the same spatial dimensions and orientations with one factor being changed, namely the appearance of the environmental boundary. It would be much more difficult to set up two spaces in the real world where the rooms were the same size with the same objects in them, with the only difference being the presence of a doorway or not, or whether the rooms were divided by a corridor or a doorway. However, with VR this issue was resolved as it allowed us to create the spaces needed that we otherwise would not have been able to make otherwise. And this is only one of the ways in which VR demonstrated its utility. We could also create more fantastical or unrealistic environments, such as a space station, which would allow for the manipulation of gravity and the positioning of objects, while also ensuring the environment met the needs of the study. On top of the high level of control and creativity that VR allowed, a sense of immersion was also an important objective to achieve. Seeing as ecological validity is an extremely important tenet of this project, and the topic is looking at scene boundaries, it was important for the participants to be experiencing as close to a real-world experience as possible. VR allows this, being highly immersive, while allowing for freedom of movement and exploration that makes the participants feel as though they are a part of the scenes they are seeing. This level of immersion would not have been possible with images on a screen or

more traditional computer tasks, and these studies were developed to demonstrate alternative ways of looking at more traditional research.

1.8.4 Research Questions

Based on the aims and objectives of this project, a number of research questions have been developed. Researchers exploring event segmentation and memory performance suggest there is a large influence of boundaries on recall, and so, the first research question of this project is “how influential is event segmentation on memory performance?” Following on from this question, there are arguments for whether event segmentation is beneficial or detrimental, with a larger body of work supporting a negative effect of event segmentation. However, this perspective has some theoretical concerns around generalisability to real world environments, and so a follow up research question is “whether event segmentation results in positive or negative effects on memory performance when tested in more complex and closer to real world environments?”

There is also a lack of clearly defined parameters or conditions under which we would expect to see a stronger or weaker influence of event segmentation on memory performance. While there has been an interest in whether there is a influence on memory performance, there has been comparatively less research exploring what factors may be influencing these reported effects. Based on this lack of clarity, another research question for this project is “what aspects and characteristics of an environment or boundary result in more severe influences on recall and memory performance?”

Finally, there has been little research exploring how the individual understands event segmentation and how environmental boundaries and segments are being perceived. Understanding the perception of the process of event segmentation can open up more avenues of research ideas and expand our understanding of the process. And so, the final research question of this project is to answer “how do we perceive event boundaries, and are we aware/ conscious of the influence they have on our perception and memory of a space?”

**Chapter 2 -
Do doorways cause forgetting?**

Chapter 2 - Do doorways cause forgetting?

2.1 Introduction

2.1.1 Doorways Cause Forgetting... Or Do They?

How we understand a continuous stream of information from the world is essential to understand how we are able to remember and organise information. The Event Horizon Model is a proposed model to explain how we segment a continuous experience and how we remember those segmented events. The EHM considers multiple factors when looking at the effect of segmentation on memory, for example, competitive and non-competitive stimuli, retrieval interference, and identification of event boundaries. However, when we look at the body of research carried out around the EHM there is a large body of work investigating the influence of spatial event boundaries, and how they cause forgetting. A problem with exploring event boundaries is that the way event boundaries are defined often varies between studies (Clewett & Davachi, 2017), and so, it is more difficult to identify individual important influences on these memory effects. Radvansky and Zacks (2017), argue an event boundary is created when a key feature of an event has changed and the event model is updated. When looking at spatial memory, a location change would register as an event change, and so the doorways between those location changes are an easy event boundary to identify. However, a focus on spatial event boundaries in this research has resulted in other aspects, such as relationship between segments, contextual knowledge, and the nature of the space, are being somewhat neglected in research. Spatial event boundaries are not emphasised as a determining factor for memory effects within the EHM. Throughout the model, more emphasis is placed on the objects in an environment, whether they are competitive or not, and the causal network between events, where people can derive a temporal sequence of events through a causal structure, as they make up three of the five principles of the model. This model was proposed to explain how we make sense of real-world environments, and so the focus cannot be on spatial event boundaries alone.

As discussed in the previous chapter, as research continues to be carried out, more mixed results on the effect of doorways on memory are now being found. Initially, however, a large number of studies were suggesting doorways have a

significant detrimental effect on memory performance for stimulus learned in spaces, with crossing through a doorway leading to lower recall scores for objects associated with those spaces than when there is not a contextual shift (Radvansky et al., 2015; Pettijohn & Radvansky, 2016, 2018). These studies include testing whether you need to physically walk through a doorway or if imagining crossing through a doorway is enough to cause forgetting (Lawrence & Peterson, 2016), investigating if doorways affect memory more when they are physical or visual boundaries (Negen et al., 2020), testing whether bringing objects through doorways effects the memory for that object (Radvansky & Zacks, 2017). Despite expanding how participants are engaging with doorways, these studies continued to find doorways to be a detriment to memory performance, regardless of the form they took or how participants walked through the space with objects.

The EHM as a model explains that when we segment information, it can have both positive and negative effects on memory. Yet, the pattern emerging from empirical research is a focus on the detrimental effect of doorways on memory, where crossing through a doorway leads to reduced recall ability for a given space. The model also considers more than only the importance of the boundary, as the model looks at the importance of the objects being remembered, features of the environment, as well as the event boundaries. If the multifaceted nature of the model was also explored in research, perhaps we would see a mixture of positive and negative effects of segmentation on memory, and be able to identify when these components come together to result in a positive or negative effect.

Attention should be brought to the topic of what is considered to be an event boundary, as previous studies have a limited definition. As discussed in Chapter 1, event boundaries can be the result of a number of varied factors, and while environmental features such as doorways are a type of event boundary, so is having an overarching goal. For example, completing your morning routine, as well as the carrying out of individual tasks, for example, the individual actions that make up that morning routine. Researchers are becoming more conscious of the complexities of goal states with event segmentation, as demonstrated by Wang et al. (2024), who call for an expansion of our understanding of the event-boundary triggering process to include affective states, goal states, and motivational states. However, the current research around doorways and visual environments does not offer much consideration to these factors; however, memory and the processing of visual information does not happen in isolation, so it is difficult to attribute these findings to a doorway alone. Thus, due to the simplification of event boundaries to only a doorway in previous studies, the

claim of “doorways cause forgetting” should be taken with a grain of salt. When the doorways are presented in a space that we have contextual knowledge for and associations with, for example, walking through multiple rooms to carry out our full morning routine, where other factors are now influencing memory both positively and negatively, do doorways still cause forgetting to the extent that previous research claims? And in this example, are doorways being perceived as significant event boundaries at all, or is it that in context, and with complex goals in mind, other forms of event boundaries take priority?

We are starting to see more of a pushback against this idea of doorways causing forgetting, with more recent research finding inconsistencies in the effect of doorways on memory. When presenting participants with realistic environments which are closer to real world experience, incorporating touch and sound, as well as vision in a VR environment, several researchers have failed to identify a significant effect of doorways on forgetting. They instead find signal detection was impaired when participants responded to probes after moving through doorways (McFadyen et al., 2021). Similarly, as the act of walking through a doorway is often used as the explanation for the forgetting effect, when research focused on locomotion techniques, whether participants were instantly teleported between spaces or had to physically walk through doorways, again, no significant differences in memory performance were found (van Gemert et al., 2024). The findings of this study highlight that doorways themselves do not draw out a unique forgetting effect, as there is no difference in moving between spaces by other methods, and that observed effects of forgetting in the current body of research may be overemphasising the role of doorways.

Still, the number of studies which claim doorways cause forgetting far outnumber those with alternative findings, and so it seems that overwhelmingly, doorways have a negative effect on memory. Table 2.1 provides a summary of studies investigating event segmentation and their results. However, is this a result of the process of walking through doorways, or is there an issue with results being reproduced in studies having little methodological variance between them?

Table 2.1*Summary of Studies Investigating Event Segmentation, and their Findings*

Researchers	Methods Used	Findings
Buckley et al. (2022)	Participants given 15 minutes to freely explore 6 buildings and learn the location of 36 objects viewed on a laptop. Movement was with directional keys	Participants could remember what building objects were in, but not where in the building
Horner et al. (2016)	Participants navigated a series of 48 rooms displayed on a monitor, where rooms contained two tables with one object each, then completed a recognition task for objects	The presence of a spatial boundary at encoding (a doorway between two rooms) impairs participants' later ability to remember the order that objects were presented in.
Lawrence & Peterson, (2016)	Participants explored either an open or divided space, then were taken to a different room, presented with an abstract image, and asked to imagine walking through the room, and after the mental walk had to pick the correct image from 10 images	When the mental walk occurred through a divided space, identification performance was worse than those who explored the open space.
Li et al. (2025)	Participants acted as salespeople in VR where they engaged with both spatial boundaries (booths) and conceptual boundaries (customer requests). Memory was tested with a recency discrimination task	Conceptual boundaries, and not spatial boundaries, resulted in impaired sequence memory.
Logie & Donaldson (2021)	Participants viewed a series of identical rooms where words would appear on a grid to learn. Movement was automated. Participants were tested by writing the words they remember seeing in any order.	Segmenting information with spatial-temporal gaps results in an increase in clustering and an increase in the number of words remembered during later tests
McFadyen et al. (2021)	Participants explored an immersive VR environment with a headset and wireless controllers, where participants could move objects. Participants' hit and false alarm rates to memory probes for items recently encountered was measured	No significant effects of doorways on forgetting were observed

Pettijohn & Radvansky (2016)	Participants explored a 55-room series with a computer screen and controller where they were asked to pick up and place down shapes through either a doorway or no shift room. A probe appeared and participants had to identify if it was the object they carried.	Error rates were lower and response times were shorter when there was no context shift (no doorway), in comparison to when a doorway was present in the room
Pettijohn & Radvansky (2018)	Participants either explored a 55-room series (either no doorway or with a doorway) picking up and placing down shapes, or passively observed the participants doing the exploration. Probes were similarly used to assess memory	Memory performance was worse for both active and passive participants when there was a contextual shift with a doorway, however, less so with passive participants
Radvansky et al. (2015)	The same procedure and materials were used as in <i>Pettijohn & Radvansky, 2016</i>	Memory was disrupted for both younger and older adults when walking through a doorway
van Gemert et al. (2024)	Participants had to place objects in a box, carry the box and place it down by either walking or teleporting through an open room or a room separated by a doorway. An object recognition probe task inspired by Radvansky et al., 2015 assessed memory	No difference in object recognition performance due to the presence of a doorway nor locomotion technique was reported

2.1.2 The importance of replication

Empirical rigour is an extremely important part of psychological research, and a topic which has been a focus of attention due to the Replication Crisis (Maxwell, et al., 2015). This has led to a crisis of faith in a lot of psychological research, questioning key theories from the past. This crisis resulted in a period of self-reflection and reform, where there was a large focus on methodological and statistical practices to prevent future studies from suffering from the same issues (Wiggins & Christopherson, 2019). This reflection led to reducing noise by increasing experimental controls and encouraging publication of replication. While this reflective approach to research is good for producing controlled experiments focusing on the processes we are interested in, it can lead to losing sight of the fact that these processes do not work in isolation in highly controlled situations. For example,

research surrounding event segmentation consists of a large number of studies supporting the idea that doorways can cause forgetting. While this series of work does offer some compelling insight into the effect of doorways on memory, there could be more variation in experimental design to reveal more on the nature of event segmentation, such as using more complex environments. Studies which adopt a different paradigm have reported alternative findings, where crossing through doorways can have no, or positive effects on memory, dependent on the context they are presented in (McFayden et al., 2021, Li et al., 2025). In McFadyen et al. (2021), participants were given free reign to explore and provided with controls that allowed them to pick up objects, meanwhile Li et al (2025), asked participants to roleplay and cross boundaries for customer requests. Li et al. found that conceptual boundaries, not physical boundaries, had a significant influence on memory performance, highlighting a different perspective on what a boundary can be in this area of research. This approach of using more complex environments with more involved tasks remain a small minority of the body of literature on event segmentation yet are more representative of the multifaceted nature of the EHM.

A lot of the current research supporting doorways causing forgetting often focus on rote memory and temporal order of words, or objects presented in empty environments. In a review by Wang et al. (2023), they make the argument that decision making is underappreciated when looking at event segmentation. On the other hand, temporal order of words are being used to test multiple internal processes, such as goal orientated memory, affective states, and motivational states. They concluded that moving forward, the experimental paradigm should be expanded to be more representative of real-world scenarios.

We see the effect of expanding this method of testing where those studies that find alternative results look at other aspects such as movement behaviours or multimodal integration, adopting a deeper look at the process of event segmentation (Buckley et al., 2022;). Buckley et al. (2022), allowed participants to explore different buildings for 15 minutes, and found participants could remember what building objects were in, but not where in the building. These contrasting studies tend to use more complex environments or give more control to the participants, and thus raises a question. If results are changing when participant engage in more complex tasks in more realistic environments, how big of a consideration should we give to ecological validity when testing theories?

2.1.3 How important is ecological validity?

While it seems uncontroversial that ecological validity is important, its level of importance becomes more debatable in practice, with some researchers opting for highly controlled lab experiments. There are numerous reasons why this may be the case, such as how developed a theory is and on what the concept being tested. For example, the EHM is attempting to explain how we make sense of a continuous stream of information and how we break up conscious experience into discrete events which can be retrieved at a later point. Due to the focus on continuous experience and a large volume of information from complex environments, it would stand to reason that ecological validity should be a priority during experimentation, to determine if the model is appropriate for real world application. However, the model is complex and multifaceted, and at beginning stages it is important to look at individual components in more controlled environments to see if the model is worth pursuing and developing, or if a different approach should be taken.

What this approach has meant for the EHM is that there is a lot of internal validity around the research into the topic, where the cause and effect of doorways leading to forgetting when tested in these conditions cannot be explained by other factors. Within the study of event segmentation, we see this with the early works of Radvansky (2012) and Radvansky and Copeland (2006) where they took environmental boundaries, and looked at its effect on memory order for lists of words and objects. In these studies, there is a clear relationship established with the role of doorways on forgetting under these conditions. However, once these results where memory for objects was worse after moving to a new room were found, these studies should have developed to include more complex tasks, or environments that we may see in the real world to see if the findings stand when tested more ecologically valid situations.

However, the importance of ecological validity was not reflected in the , previously discussed studies either taking place in empty rooms. For example, in Horner et al (2016), the goal was to understand how recall is bounded in time and space during a continuous stream of information tested in an environment with very limited information and identical environments, thus the testing environments did not reflect the goals of the research. Another example is taking movement away from

participants and forcing them along a predetermined path, which is not representative of how we move around environments in the real world, for example, Logie & Donaldson (2021), where the goal of the research was to assess learning stimuli as a function of the presence or absence of spatio-temporal gaps through the presence of physical boundaries during encoding. Researchers understand how complex event segmentation can be, as they often cite the EHM in their work, so it is surprising that some researchers chose to make their experiments unrepresentative of real-world experiences through the simplification of the environments or exploration experience. The EHM was proposed to explain memory with a continuous stream of information, and to understand the complexities of that experience we need to adopt a more holistic approach to event segmentation instead of reducing environments to individual components, such as doorways, which may not have as strong of an influence in context.

2.1.4 Aims and objectives for experiments 1 & 2

Given mixed findings about the effects of doorways on forgetting, particularly when approached with naturalistic methodologies, we sought to establish a clear effect of doorways on memory in more complex environments. The results of this experiment could be impactful because not finding results consistent with doorways causing forgetting or finding a mix of positive and negative effects to memory performance would suggest that future research around the EHM and event segmentation could take more account of the complexities of real-world environments. Furthermore, the EHM could be more explicit as to what real world factors would result in memory effects under what circumstances.

Whether the effect of forgetting is still as prevalent when there is not a focus on temporal order, such as recalling a list of words or series of objects in the correct order, and in a more complex environment, is a question this study aims to clarify. We created a study where participants explored a virtual environment (a large office, with either a boundary bisecting the space or it was left open plan), where they could freely move around. Given our interest in keeping the experience as realistic as possible, we ensured people could walk around naturalistically and tested memory for real objects in the space (cf. artificial lists of words on the wall/s (Logie & Donaldson, 2021)). To do this, we opted for a free recall task and object recognition test, choosing a more novel form of testing memory that puts the emphasis on stimulus in the environment and how it fits in, instead of only whether the

stimulus was present or not. Based on the current body of research, we would expect to find that those in the boundary conditions, where a space is divided by a doorway, perform worse in the memory tasks, a free recall task and object recognition task for objects in the space, than those learning a space not divided by a boundary.

As a follow-up, in experiment two, the environments were now empty rooms with lists of words presented on the walls, where participants would learn lists of words presented in either an open space, or a space bisected by a doorway. The results from this experiment would then be compared with the results from experiment one. The words presented would be of objects or features of the space in experiment one, with the number of words in experiment two matching the number of objects presented in experiment one. As a result of similar number of stimulus to learn, we could use the same free recall task and similar recognition test, and the scores would be comparable across both experiments. With this approach to the results, we will be able to make a cleaner comparison to the current body of research surrounding the EHM, while highlighting the differences in findings from experiment one. Any differences in results between the two studies should highlight the importance of realistic testing environments. In order to highlight the differences between using lists of words and complex environments, we streamlined the conditions and experiment, where we focused on comparing differences between environments bisected by a doorway and an open environment with no doorway, this way we could isolate and effects of doorways found.

We were also interested in whether the properties of a boundary have an effect on memory. Previous research has shown differences in memory performance when focusing on the physical and visual properties of an event boundary. This work reported that looking like a boundary was found to be more important than acting as a physical barrier in accurately recalling object locations when tested later (Negen et al., 2020). Thus, we had one condition where the boundary was a normal doorway, and a second boundary condition was added where for some participants there was a shimmer bisecting the room. The shimmer was a translucent orange haze bisecting the room which could be crossed at any point. In comparison, the doorway could not be seen through, resulting in limited view of the other half of the environment, and you could only traverse the doorway at one point, being the doorframe. The inclusion of the shimmer condition was because we wanted to also look at whether it was

doorways, the act of walking between two discrete rooms, or whether any perceived boundary would produce the same forgetting effects.

A final aim of this study was to look at how long the effects of event segmentation lasts. Research into the effects of boundaries on memory performance primarily focus on immediate recall, with most of the previously discussed research testing memory immediately after the presentation of the stimulus. However, some research has explored the long-term effects of segmenting, finding that the effects can last up to one month (Flores et al., 2017). This study found that the level of details in memory recall changes with time. Immediate recall focused on specific information and intricate details, where a month later, participants recalled more so gist and themes of the observed event. Therefore, we conducted memory tests immediately after exploration, as well as a week later to investigate how stable segmenting memories could be.

While the current body of research would expect those in the boundary conditions to perform worse than those in the open condition, enough alternative findings have been reported to cause doubt in the strength of this forgetting effect. With the changes in experimental design focusing on replicating more realistic conditions, we believe there will be a difference in performance, however, the direction of that difference remains somewhat unclear. As a result, we have opted for a non-directional hypothesis.

Based on these aims and the previous work on the topic, we had the following hypotheses;

- H_1 : There would be a significant difference in both free recall and recognition memory performance between the doorway and no boundary conditions
- H_2 : Differences in memory performance between boundary conditions would be consistent one week after exposure to the scene,

Based on previous work and the findings of experiment one, experiment two had the following hypotheses;

- H_1 : There would be a significant difference in both free recall and recognition memory performance between the doorway and no boundary conditions
- H_2 : There would be a significant difference in memory performance across the list of words and objects orientated environments.

2.2 General Methods

Throughout this project, a study paradigm was developed which would serve as the structure for multiple experiments. Here I will outline the template of this paradigm for reference, and all variations or adaptations will be discussed in each experiment's respective methods section. This template will be relevant to all experiments in the current chapter and Chapter 3.

2.2.1 Participants

For all experiments, adult undergraduate participants were recruited from the University of East Anglia, using the School of Psychology's Research Participation Scheme. Students were offered course credits for the completion of the respective study. Ethical approval was received from the School of Psychology for all experiments.

2.2.2 Design

Each experiment used a between participants design, and each participant only completed the study once to avoid practice effects associated with familiarity with the virtual environment. However, participants were able to take part in multiple experiments due to the change in environments, independent variables, and goals of the respective study.

Independent variables were differences in the environments, which could be associated with the presentation of the boundary (Experiment 1 & 4), or the presentation of the space (Experiment 2 & 3). For example, for the boundary focused experiments, in Experiment 1 we look at differences in memory performance when a boundary is present or not, and in Experiment 4 we look at differences in memory performance when the boundary is a doorway or corridor. For the space presentation focused experiments, Experiment 2 contrasted memory performance between complex and empty spaces, and Experiment 3 contrasted aesthetically similar and

different spaces. The conditions were made up of either the same spaces (Figure 2.1), or two different spaces where the objects in the space were paired in order to make comparisons as fair and accurate as possible (Figure 2.2). All spaces were of the same size and dimensions to limit differences of global processing or navigational processes on memory performance.

Figure 2.1

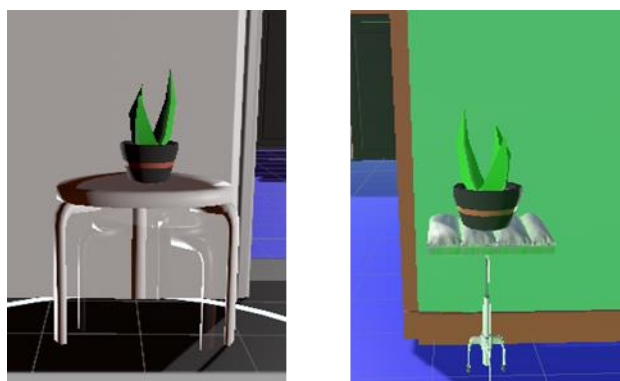
Example of Different Boundary Presentations in the same Environment



Note. Figure shows an example of the appearance of the boundary between the three separate conditions for Experiment 1, one without a boundary dividing the space (left), one where there was a doorway bisecting the environment (middle), and one with a shimmer dividing the space (right).

Figure 2.2

Example of Objects Paired Across Conditions in Aesthetically Different Environments



Note. Figure shows how objects were paired when comparing two aesthetically different scenes in Experiment Three, where the potted plant on a stand is the same arrangement and orientation between both scenes, only aesthetically different.

The dependent variables in each experiment were the performance on both the free recall and forced choice object recognition tests. For the free recall test, participants were prompted to write down as many objects as they remember seeing in the environment, and to include the number of the objects. If there were multiples of the same objects, for example, with chairs or desks, they would be asked to write how many of these objects were present. The lists of objects were marked with correct objects counted to give a free recall score. The maximum number of objects which could have been recalled were 50, making for a maximum score of 50. For objects with multiples, they would be given marks for the number of objects they said, unless over the correct count, where one mark was taken off for each object over. For the forced choice object recognition test, participants were provided with three images from the environment, where only one was correct and accurate to the environment they experienced (Figure 2.3). The incorrect images could have objects in incorrect locations or orientations, or with an altered appearance, such as different size or colour. Their score was made up of the total of correct identifications the participants made, of which there were 25 trials, making for a maximum score of 25.

Figure 2.3

Example of Presentation of Stimuli in a Forced Choice Object Recognition Trial



Note. Figure shows an example how an object may be presented in the Forced Choice Object Recognition test, where they would need to select which image is representative of the location of the kettle in the environment they explored.

2.2.3 Materials and Apparatus

An HTC Vive Head Mounted Display (HMD) was used, along with HTC motion trackers, which enable participants to freely walk around and have their movements fully and accurately represented in the virtual environment. The VR environment was run through a customised PC, which was a customised HP Z4 G4 workstation, with 64GB RAM and an Intel Core i9-9920X CPU, consisting of 12 cores and 24 threads with clock of 3.5 GHz. The CPU could run games with frames per second ranging from 151.1 to 335.1 FPS depending on the settings. As we wanted to provide as smooth and consistent running rate as possible, we prioritised performance to ensure there would be as little lagging or dropped frames as possible. Framerate was capped at 60 FPS to prevent variations in framerate. A stopwatch was used for the timer and a Dell laptop was used for the participants to conduct the follow up memory tests on.

Unity (Unity Technologies, 2021) was used to develop and run the virtual environment, with objects either downloaded from the Unity Asset Store (<https://assetstore.unity.com>) or created by the researchers themselves in Unity and Blender (Blender 3.0, 2021). Any components of the environment where the code needed to be altered was conducted using C# and the researchers own code. Some environments contained moving elements or would be controlled by the participants such as sliding doors. The environments consisted of two rooms, around 4m x 8m x 3m, adjoining along one of the 8m walls, to create an 8m x 8m square when measuring the two rooms together. Gorilla (<https://gorilla.sc/>) was used to create and run the free recall and forced choice object recognition tests, with the exception of Experiment 1, which was created and conducted using Qualtrics (<https://www.qualtrics.com/en-gb/>). Both the free recall and forced choice object recognition tests were created by the researchers. They were inspired by previous research into event segmentation and the tasks that were used, such as the series of studies by Radvansky and Pettijohn (Radvansky et al., 2015; Pettijohn & Radvansky, 2016, 2018). SPSS was used for data processing and statistical tests, the data was reformatted in Excel and imported into R Studio for the creations of data visualisations and graphs.

2.2.4 Procedure

Before beginning each experiment, participants were given an explanation of the experiment and informed of what would be asked of them, so participants were conscious of

the experiment being a test of memory before beginning. Participants were also advised on issues of motion sickness and visual acuity at this point, for further details on the research and lab protocols used, refer to Appendix (Insert later).

Participants were instructed that they had five minutes to walk around and explore the environment, however, they could come out early if they wanted. Participants would walk around the room(s) and freely explore, while being aware that a memory and object recognition test would follow.

When the participants were ready to proceed, they completed the two memory tests on a laptop. The first was a free recall task in which the participant listed as many objects as they remember seeing in the environment. The second was a forced choice object recognition test, where they had to choose the correct image from a series of three options (see Figure 2.3). Participants could take as long as they wanted when completing both tests. These tests were consistent across four experiments, with the only differences being the stimulus being presented in the object recognition test, which matched the those presented in the test environment.

2.3 Experiment 1 Methods

2.3.1 Participants

Sixty-nine participants completed the experiment, with a mean age of 20.91 years ($SD = 4.26$ years), made up of 49 female, 17 male, and 3 non-binary participants. The sample size matched the n of similar experiments using VR, Pettijohn and Radvansky (2016) tested between 40 – 52 for four different experiments, while Pettijohn and Radvansky (2018) tested 48 and 88 participants for Experiment 1 and 2, respectively.

A power analysis was conducted using the effect sizes from Pettijohn & Radvansky (2016), due to the importance of the experiment to this study, and the similarities in experimental design, where they used 2x2 ANOVAs throughout the study. Based on their reported effect sizes, using g^* power, it was determined that an acceptable number of participants for our 2x3 experimental design to achieve a power of 0.95 would be 27 total. However, due to the differences of between the number of

groups between the experiments, with our experiment using three groups as opposed to two, a post hoc power analysis was conducted to assess the achieved power of the experiment. With a total $n = 69$, the achieved power of this study was .99, and so, the study was appropriately powered.

2.3.2 Design

A between subject design was used where the IV was whether a boundary was present or not, and what form it took (doorway, shimmer, or no boundary), while the DV's were the number of objects correctly recalled in the free recall task and score on the forced choice recognition test. The experiment consisted of two phases. The first phase was carried out in person, and consisted of exploring a virtual reality environment, immediately followed by test of free recall and short-term recognition. The second session was carried out a week later online with the same free recall and recognition tasks as in the test phase of the first session.

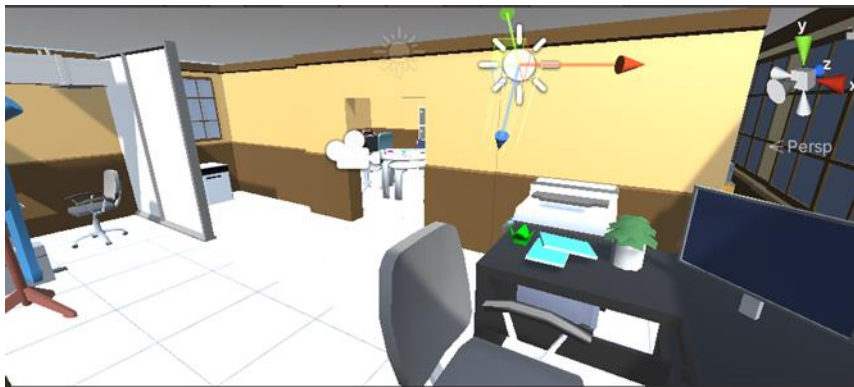
2.3.3 Stimuli and Materials

The three different environments (Figure 2.4) acted as the independent variable for this study and participants only experienced one of the environments. The room used was an office space was created in Unity with assets both downloaded from the Unity store, as well as created by the researchers. The composition of all three spaces were identical in terms of object placement, size, colour, and orientation (Figure 2.4). The location of the boundary was also consistent across the doorway and shimmer condition, with the thickness of the shimmer matching that of the doorway. The doorway was created from the same assets as the walls of the room, where the shimmer was a blank plane, where the opacity was reduced, and a colour placed over it to make it stand out a bit more in comparison to a colourless shimmer.

For the tests used to assess memory performance, see the general methods above (chapter 2.2.5)

Figure 2.4

The Conditions in the Office Space.



Note. Top; The “No boundary” condition with no boundary bisecting the office space, middle; the “Doorway” condition with a doorway bisecting the office space, bottom; the “Shimmer” condition, with a see-through barrier bisecting the office space.

2.3.4 Procedure

For the procedure of part one of the experiment, refer back to the procedure outlined in the general methods (chapter 2.2.4)

. Participants spent five minutes exploring the virtual environment, in which they could freely explore as they saw fit. Upon completion of the exploration phase,

participants were able to rest if they needed, or they could immediately move onto the memory tests. No distractor task was used between encoding and retrieval, as the moving between VR and testing memory in the real world was deemed an appropriate disruption for the experiment. The participants first completed a free recall task then completed a forced choice object recognition test.

Participants received the instructions “You have five minutes to freely explore and learn the space in how you see fit. You can move around the space freely and can explore the entire space. If you do not need the full five minutes or are feeling dizzy or disorientated, you can end this phase early”. While participants were able to freely move around the space, and cross between the boundaries as many times as they saw fit, there was no meaningful differences in exploratory behaviour, such as the amount of times crossing the boundary, or time spent in each room, when analysed.

For part two of the experiment, participants were emailed a Qualtrics memory experiment one week later, in which they were asked to complete at the same time and the same day as they completed part one of the study. All participants completed the online version of the study one week after the initial exploration session. This online part of the study consisted of both the free recall, and force choice recognition tasks again, with the order of the questions and stimulus for the force choice task reordered. There was no time limit for the tests. On completion of both parts of the study, participants received course credits for their participation.

2.4 Results

2.4.1 Free Recall

We also investigated the effect of boundary type (no boundary, doorway, shimmer), on free recall performance, when assessed both immediately after exploration and one week later. The mean score between boundary conditions were similar, both immediately after exploration and one week later (Table 2.2).

We used a mixed design; 2 x 3 ANOVA compare the differences between immediate and long-term performance for free recall in the three groups (Figure 2.5). Results indicated significant differences between short term and long term performance, $F(1,58) = 20.06$, $p < .001$, $\eta_p^2 = .257$. Immediate free recall performance ($M = 27.66$, $SD = 8.58$), was

significantly better than when tested a week later ($M = 22.98$, $SD = 8.68$). However, no significant differences were found between the three boundary test conditions, $F(2,58) = .823$, $p = .44$, $\eta_p^2 = .03$, nor a significant interaction between time of testing and the boundary condition, $F(2,58) = .11$, $p = .898$, $\eta_p^2 = .004$.

Table 2.2

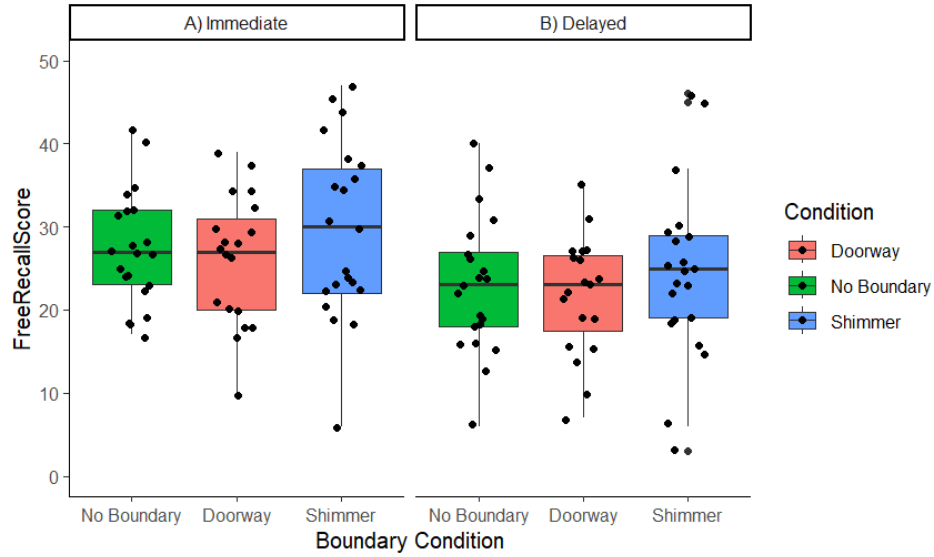
Average Free Recall Score by Boundary Condition Immediately after and One Week Post Exploration

Scores	<i>M</i>	<i>SD</i>	<i>Range</i>
Immediate			
No Boundary	27.29	6.94	17 - 42
Doorway	26.00	7.86	10 - 39
Shimmer	29.57	10.65	6 - 47
One Week Post Exploration			
No Boundary	22.90	8.22	6 - 40
Doorway	21.68	7.06	7 - 35
Shimmer	24.24	10.50	3 - 46

Note. Maximum possible score was 50.

Figure 2.5

Average Free Recall Score by Boundary Condition, Comparing Immediate and One Week Post Exploration Scores



Note. Individual scores shown in scatter layered over box plot. Maximum score in task was 50.

With no significant effect of boundary condition being found, further analysis was carried out to determine the strength of evidence for the null hypothesis that there is no significant effect of boundaries on memory performance, $F(2,119) = 1.22, p = .298, \eta^2 = .02$. With $BF_{10} = .293$, the null hypothesis is 3.41 times more likely than the alternative, considered to be somewhat moderate evidence.

2.4.1 Recognition

We investigated the effect of boundary type (no boundary, doorway, shimmer), on forced choice object recognition performance, when assessed immediately after exploration and one week later. The mean score between boundary conditions were strikingly similar, both immediately after exploration and one week later (Table 2.3).

We used a mixed design; 2 x 3 ANOVA to investigate the effects of boundary condition (open space, doorway, shimmer) and test time (immediate, delayed) on recognition performance (Figure 2.6). Results indicated no significant effect of the boundary conditions, $F(2,58) = 2.86, p = .065, \eta_p^2 = .09$, nor of test time, $F(1,58) = 2.01, p = .156, \eta_p^2 = .034$, nor a significant interaction between time of testing and the boundary condition, $F(2,58) = .47, p = .628, \eta_p^2 = .016$.

Table 2.3

Average Forced Choice Recognition Score by Boundary Condition Immediately after and One Week Post Exploration

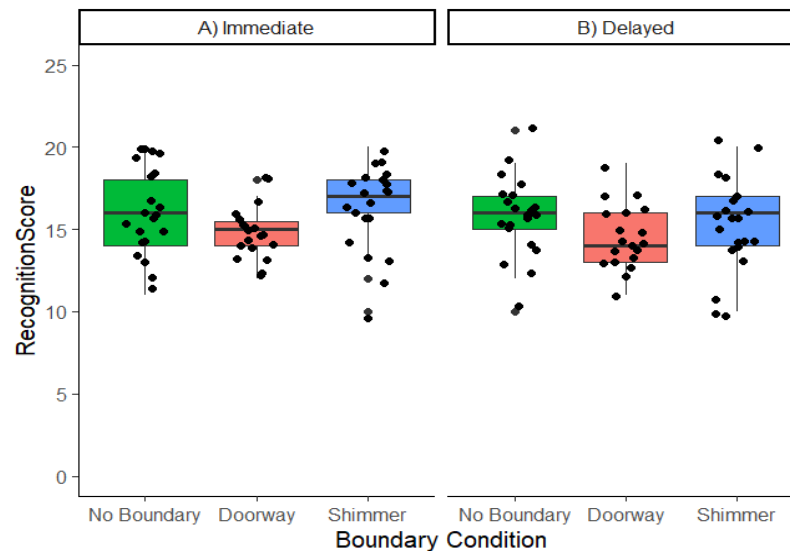
Scores	<i>M</i>	<i>SD</i>	<i>Range</i>
Immediate			
No Boundary	16.09	2.76	11 - 20
Doorway	14.83	1.76	12 - 18
Shimmer	16.29	2.55	10 - 20
One Week Post Exploration			
No Boundary	15.76	2.41	10 - 21
Doorway	14.53	1.95	11 - 19
Shimmer	15.19	2.50	10 - 19

Note. Maximum score on test was 25.

Due to how differences in the boundary conditions was nearly significant, further analysis was carried out, using 2x2 ANOVAs to assess doorway conditions against both open and shimmer separately. However, as this analysis was only carried out after reflecting on the results, and we did not have any indication doorway would be a much different condition to the other two, this analysis will not be a part of the main body, and will be available in Appendix H.

Figure 2.6

Average Forced Choice Recognition Score by Boundary Condition, Comparing Immediate and One Week Post Exploration Scores



Note. Individual scores shown in scatter layered over box plot. Maximum score on test was 25.

As no significant differences were found in the above ANOVA, we used Bayesian analysis to assess the strength of evidence for the null hypothesis, in comparison to the alternative. The Bayes Factor (BF) is used to assess the likelihood of one hypothesis being true over the other, with a BF of 1 indicating that both hypotheses are equally likely. We investigated the effect of boundary type (no boundary, doorway, shimmer) on forced choice recognition performance. The result $BF_{10} = .808$, indicates that the null hypothesis is 1.24 times more likely than the alternative hypothesis, which is considered to be anecdotal evidence that the null result is true (Andraszewicz et al., 2015). We also investigated the effect of test time on recognition performance, and with a $BF_{10} = .543$, the null hypothesis is 1.84 times more likely than the alternative hypothesis, which is considered to be anecdotal evidence.

2.4.3 Unique objects

We also conducted an exploratory, follow up analysis to examine whether participants were learning the two halves of the environment as individual spaces, or learning more general objects that were present in both halves of the overall environment, we looked at memory for unique objects (objects which appeared only in one room, and not in both). Another purpose of looking at unique object was to determine if the boundaries, or lack thereof, were creating a bias towards remembering one part of the environment over the

other. As we did not record the amount of time each participant spent in each room, looking at performance for each space was decided to be an appropriate measure to assess differences between each room. We investigated whether memory for these unique objects was influenced by the presence of a boundary by comparing the proportion of the unique objects recalled across boundary conditions. Scores were calculated by taking the percentage of unique objects recalled in each room and converting it into a percentage of the total number of unique objects in that room. All participants started in the same room, so to make comparisons between the spaces, we have labelled the room in which participants start as Room 1, and the room which adjoins the starting area as Room 2. For the no boundary condition, Room 1 (Starting Room) and Room 2 (Adjoining Room) were divided in the same location as the boundary was present in the other conditions, meaning the same objects were unique to the same space across all conditions. There were 12 unique objects in each room, meaning that there were 24 unique objects in the overall environment.

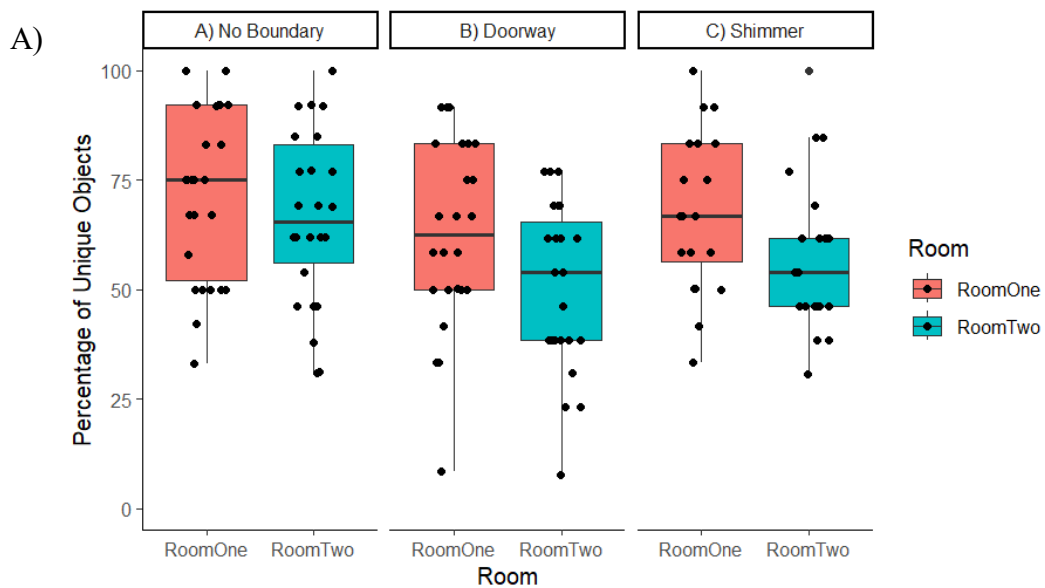
A mixed design 2x3x2 ANOVA was used to investigate the effect of boundary conditions (no boundary, doorway, and shimmer), and test time (immediate or delayed), on memory for unique objects across each half of the environment (Figure 2.7). Results indicated significant differences in memory for unique objects from Room 1 and Room 2, $F(1,63) = 26.83, p < .001, \eta_p^2 = .299$. Unique objects in Room 1 ($M = 63.30\%$, $SD = 23.39\%$), were proportionally recalled significantly more than those present in Room 2 ($M = 56.59\%$, $SD = 22.59\%$). A significant interaction was found between memory across rooms and testing time, $F(1,63) = 5.39, p = .024, \eta_p^2 = .079$. No significant results were found for boundary effects on memory for each room, $F(2,63) = 5.27, p = .59, \eta_p^2 = .016$. Finally, there was no significant interaction between the three variables, $F(2,63) = 1.79, p = .175, \eta_p^2 = .004$. The BF was also calculated for the boundary effect, and with $BF_{10} = .24$, the null hypothesis is 4.17, which can be considered moderate evidence for the null hypothesis.

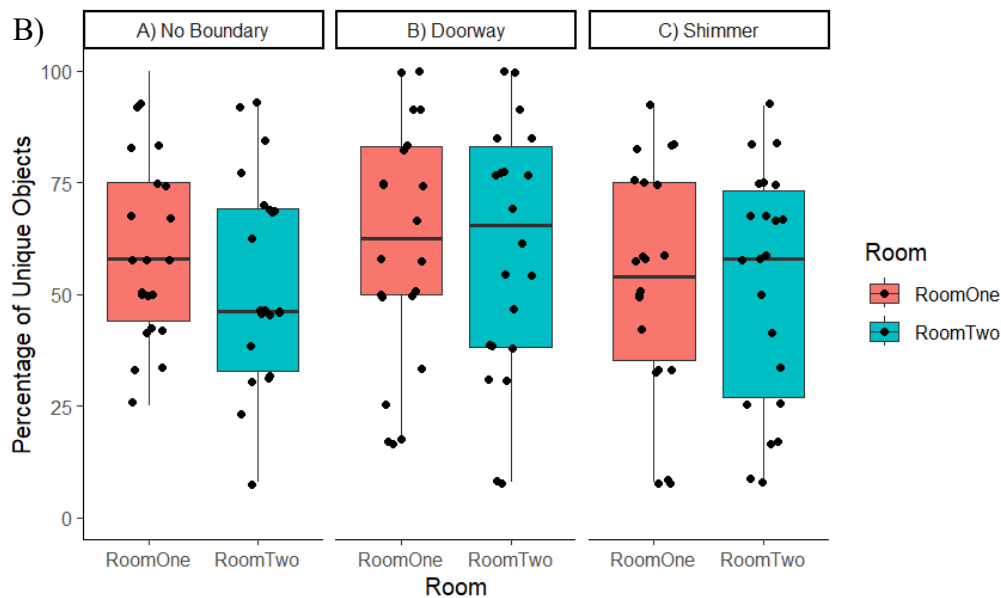
A post-hoc analysis was carried out to better understand what was driving the interaction between memory performance for each room and when the testing took place. A t-test was conducted, comparing the difference in scores between the rooms at each time, separately. Though memory performance was always better in Room 1 compared to Room 2, the relative superiority was greater when assessed immediately

($M = 10.19\%$, $SD = 17.11\%$) compared to a week later ($M = 3.23\%$, $SD = 15.06\%$); $t(65) = 2.29$, $p = .025$, $d = .41$, $CI = .897 - 13.03$. On immediate recall, there was a significant difference between the proportion of words recalled in Room 1 ($M = 68.07\%$, $SD = 20.72\%$) and Room 2 ($M = 57.88\%$, $SD = 18.76\%$); $t(65) = 4.84$, $p < .001$, $d = .60$, $CI = 5.98 - 14.40$. In comparison, the difference between Room 1 ($M = 58.53\%$, $SD = 25.04\%$) and Room 2 ($M = 55.30\%$, $SD = 25.94\%$) were no longer significant one week after exploration; $t(65) = 1.74$, $p = .08$, $d = .21$, $CI = -0.48 - 6.93$.

Figure 2.7

Relative Proportion of Unique Objects Recalled in each Room by Boundary Condition Immediately after Exploration and One Week Post Exploration





Note. A) Immediate Recall, B) One Week Post Exploration

2.5 Discussion

There is a strong body of evidence to suggest that walking through doorways negatively impacts memory performance (Pettijohn & Radvansky, 2015; Pettijohn & Radvansky, 2016; Pettijohn & Radvansky, 2018). However, with more recent research finding alternative findings when tested in more complex environments (McFayden et al., 2021; van Gemert et al., 2024), the current experiment asked several questions, do doorways cause forgetting when presented in a complex environment and naturalistic conditions? Does the appearance of an environmental boundary have an impact on any observed forgetting effect? How stable are these differences in memory performances over time? And do boundaries create a spatially localised bias?

The results of this experiment suggest that none of these questions have a particularly clear answer, reflecting that the role of doorways in the forgetting effect should be explored in further experiments. The role of doorways in memory processes is a complicated one, more so than previous research has given credit for. The results of the present study indicate that doorways alone do not have a significant influence on memory for a scene, as there was no main effect for the type of boundary in any of the free recall nor recognition tests. However, the null effects of this study are not to say that there is no boundary effect with regards to memory, instead that we do not

fully understand the extent of the boundary effect and when we can expect to see an impact on memory performance. Similarly, there could be a greater number of objects needed to test these ideas more thoroughly than was not achieved through this experiment.

However, we do see significant differences in memory performance when we look at *when* participants were tested, with testing immediately after exploration producing higher scores than delayed testing one week later being found in the free recall task. As well as when we looked at the proportion of unique objects being recalled, finding that there is a bias towards Room 1 over Room 2. With the unique objects we observe that the difference between the amount of unique objects from each space recalled gets smaller with time, indicating that as time goes on, the division in the space becomes less distinct, and participants begin viewing the environment as one space. The bias to recall more unique objects from Room 1 which was present on initial testing was no longer present after a week, indicating that the distinctions between Room 1 and Room 2 diminished with time. This interaction did not include boundary conditions, thus, regardless of whether a boundary was present or not, unique objects were recalled more evenly from both sides of the boundary one week later.

These results suggest that the effect on doorways is not as clear cut as previous research suggests. As mentioned in the Introduction, the studies this experiment were based on found consistent results that doorways cause forgetting. When free recall and forced choice recognition were immediately tested, there were no observed differences in memory performance between the three boundary conditions. Only when comparing the immediate testing to scores a week later do we observe a significant difference, where immediate testing produces higher scores than delayed testing. However, there is still not an effect of condition nor an interaction with testing time observed at this point, suggesting that *when* memory was tested had a much greater effect on memory performance than what boundary condition the participants were in.

We also looked at memory for unique objects as a way to determine if there was a superiority for one part of the environment over the other, and whether participants were focusing on generic stimuli which appeared on both sides of the boundary, or learning each half of the environment distinctly. When we look at memory for unique objects (objects only present in one of the two rooms) we see memory for unique objects in Room 1 was significantly better than Room 2. These findings support the idea that the boundaries are

providing organisation for mental representations of the space, where the information in one space may be prioritised over another. This difference was particularly evident when immediately tested, as there was an interaction between the differences in room recall and time, where one week later the difference between Room 1 and Room 2 had become significantly smaller.

From these results, we can conclude that environmental boundaries have some effect on memory performance; however, the mix of significant and non-significant results suggest that the effect is more complex than only doorways cause forgetting or improve memory. If the doorways alone were causing differences in memory performance, then we would expect to see significantly worse memory performance in the boundary conditions in comparison to the no boundary condition. However, the results of this experiment suggest that the influences of environmental boundaries are more complex than a single detrimental effect.

2.5.1 Immediate Memory Performance

When we look at immediate performance in free recall and recognition tests after exploration, there is not a significant difference between boundary conditions for memory performance. This raises some questions as to why we did not see a clear difference when previous research has consistently found that walking through doorways results in poorer memory performance. In this experiment, our sample size was quite similar to those of previous research, to ensure we did not suffer from a lack of power. The biggest difference between this study and others is the complexity of the explored environments. As previously discussed, a lot of the previous research (Horner et al., 2016; Pettijohn & Radvansky, 2018) carried out studies using lists of words or a series of objects presented in an empty space, whereas the current study uses a complex office space with a wide variety of objects. In particular, Pettijohn & Radvansky (2016; 2018) used a series of 55 rooms with a simple layout with an abstract shape to pick up and put down, with a predetermined route and a probed recognition task. There is a lot of restriction within this experimental design that does not represent the freedom of exploration offered within the real world. Similarly, a probed recognition task tests a small aspect of memory performance. In our study, participants freely explored a complex space with contextual meaning, and were

tested on both free recall and recognition, a more representative test of the complexities of memory performance. What this seems to suggest is that when we look at the role of doorways in isolation, there is a negative effect of doorways on memory performance, however, when we look at the role of doorways in a more ecologically valid environment, we do not see the same change to memory performance.

However, more recent work from Radvansky (Crockett et al., 2026) suggest that the negative effect of doorways may not be as strong as originally conceived. When a list of words was learned in either one room, or split in half and learned in two rooms, there was very little difference in memory performance. While it was theorised that learning in two spaces would improve memory for objects learned in the second room, there were also no detrimental memory effects observed between when there was and was not a contextual shift. Here we see that updating the research paradigm can show that the forgetting effects observed previously are not as consistent as previously claimed.

This idea is supported by the work of McFayden et al. (2021), who used complex environments and looked at multisensory environments, including visual, auditory and tactile stimuli, and also did not find consistent evidence that doorways causing forgetting. The virtual environment in this McFayden study was not only an empty room or a designated route that every participant took the same way through. The layout of the rooms meant that the location of the door in the room could change, objects were not in the same locations in the rooms, and the layout of the environment included forks for participants to choose which area to explore next, and rooms of different shapes. Similarly, the participants did not only see the objects or lists of words but were given two controllers (one for each hand) in which they were asked to pick up and put down objects, incorporating touch and movement into the environment, and not solely presenting the objects as visual stimulus. The design of the McFayden et al. (2021), study shows how dynamic and multifaceted virtual reality studies can be and demonstrates how future research can include exploration and variety in their experiments to replicate the variety of environments we would see in the real world.

This is not to say that doorways have no effect in memory performance, however the mixed results throughout this experiment suggest that the effects of environmental boundaries on memory performance may not be as clear or straight forward as previous studies suggest. The effect on memory seems to be more dependent on other factors, such as when the memory is being recalled and the nature of the stimuli being recalled. The EHM also

supports this idea, as it does consider the relationship between stimulus in a space, as well as the connectedness of events. It states that previous knowledge of how spaces would be laid out, or what objects are likely to be found together would aid in memory performance. However, this is something that is being lost when we reduce memory to lists of words or sequences of objects in isolation, and so it is difficult to generalise the claims the work of Radvansky and Pettijohn (2016; 2018). There is little consideration for the role of expectation and previous knowledge in these studies despite holding an important role in the EHM. Due to their approach to studying this topic, it is difficult to apply their findings to the real world as they do not test an accurate representation of real-world memory processes or event segmentation in action.

It should be noted that the paradigm adopted for this study, while similar in procedure, is different in context. In a complex environment such as those used in this experiment, objects are contextually embedded and so, memory performance will be inherently different from the use of a more abstracted list of words. This is especially important for recognition tasks, where the context will be one of the largest factors determining the correct recognition of the objects. This inherent difference is why Experiment two was conducted and is so important for this project, where we need to highlight the similarities and differences between contextually embedded and more abstracted learning scenarios. However, this does not take away that this is a necessary update to the experimental paradigm that was previously used to be more representative of how event segmentation may work in real world scenarios.

The memory tests carried out in the current experiment are different from other works in the field, placing less emphasis on temporal order than previous works, where the stimulus was presented in a certain order and one at a time (Logie & Donaldson, 2021; Wang et al., 2023). However, we believe our tests to be an appropriate measure for the effects of event segmentation and the role of doorways, as the measures for memory and forgetting go beyond temporal order and mixing up stimuli. When we expand how we are testing forgetting beyond recalling the temporal order of stimuli to include free recall and some objects not being recalled, as well as the ability to be able to correctly recognise objects and parts of the scene, differences in memory performance produce a mix of significant and non-significant results.

2.5.2 Long Term Memory Performance

Similar to immediate memory performance, we do not see any significant differences between boundary conditions when tested a week later in recognition or free recall. These findings also suggest that boundaries alone are not enough to produce differences in memory performance. If there were long term effects of event segmentation, we did not find evidence that they were strong enough to produce a significant difference in memory performance. Previous research (Flores et al., 2017), suggests that segments change the quality of the memory over periods of time, going from more detailed and fine grained, to more generalised as time goes on. However, we do see time having an effect on overall free recall performance. Participants performed significantly better in the free recall task on immediate testing than a week later. These findings suggest that memory performance is not particularly aided or hindered by the presence of event boundaries.

2.5.3 Unique Objects in Environment

When we look at the proportion of unique objects remembered in the virtual testing environment, we see a significant difference in the proportion of unique objects recalled from each of the rooms, with Room 1 having a higher proportion of its unique objects recalled than Room 2. We also see an interaction with time, where the difference in unique objects recalled from each half of the environment gets smaller after one week. These findings suggest that upon immediate testing, participants are still remembering the spaces in detail, and being able to call objects they only saw once in one part of the space. However, after a week, participants have a more generalised mental representation of the space, as differences between Room 1 and Room 2 diminished, relying more on the objects that were present across both rooms and appeared multiple times, while forgetting more of the unique objects. However, once again, we do not see a significant influence of the boundary condition. If doorways had such an effect on memory performance that several studies had been carried out showing how they lead to forgetting when recalling information, it would stand to reason that we should have also seen a boundary effect here. The lack of boundary significance on memory performance could indicate that the forgetting effect claimed by previous research is not as consistent as the body of work would suggest.

From the results of the experiment, it is difficult to support the claim that the presence of a boundary is causing forgetting, as participants were allowed to freely explore the space, including crossing the boundary as many or few times as they liked. If crossing the boundary was the influential factor, then it would stand to reason that the effect would be cancelled out as participants crossed back and forth multiple times and thus forgetting would occur for both sides of the space. What we are seeing instead is the same superiority for the same half of the space when the room is divided. It appears as though we are seeing an immediate organisation of the space into two distinct halves, where the environment is recalled in more detail, being able to recall objects which only show up in one room. The discrepancy between Room 1 and Room 2 implies a bias towards the starting room, however, as time goes on, this effect becomes less. The proportional recall between the two spaces become similar levels, suggesting the distinction between the two rooms is less apparent, and as recall of unique objects is overall worse one week later, it also suggests participants are recalling more general information, recalling the environment as one large office space.

When analysing the unique objects in the environment, we were not expecting to see such a bias towards the starting room, instead anticipating that a boundary effect may have become more prominent. One explanation for the discrepancy between Room 1 and 2 may be that upon initial exposure, the starting room had a more developed cognitive map form with more cognitive load dedicated to the processing of the space. When participants moved to the next room, they already had a significant level of cognitive effort processing the first room, that less resources could be dedicated to the second room. In this scenario, the Room distinction provides a clean organisational point to reduce the amount of information that needs to be learned all at once, and with this organisation, there is a primacy bias where the information first encountered and organised is processed more effectively than the more recent information which has to be learned after the learning process has started.

2.6 Experiment 2

We wanted to draw closer comparisons to previous research while utilising the paradigm of Experiment 1. The purpose of this follow-up was to highlight the

influence of test environments. If we are able to find a boundary effect using lists of words in empty rooms, it would emphasise that the non-significant boundary effects of Experiment 1 may be evidence for the forgetting effect of doorways not having a significant influence in real world environments.

2.7 Methods

As this study was developed with the intention of comparing to Experiment 1, see section 2.3 for a more comprehensive explanation of the methods.

2.7.1 Participants

Forty-eight participants completed the experiment, with a mean age of 20.35 ($SD = 4.12$), made up of 37 females, 14 males, and 1 non-binary participant. In order to be able to compare results with those from Experiment 1, we made sure the individual conditions had a similar number. The conditions in Experiment 1 were made up of 23-25 participants each and so we collected 24 participants for each condition in Experiment 2. We wanted to keep the number of participants consistent with the previous experiment for fair and appropriate comparison. Similarly, participants were randomly allocated to each condition, and were not matched for any variables.

Due to the results of this experiment being explicitly compared to those of the previous experiment, a power analysis was not conducted as it was deemed to be more important that the number of participants per condition matched those of the first experiment for appropriate comparison.

2.7.2 Stimuli and Materials

Whether a doorway was present or not in the environment acted as the independent variable (Figure 2.8), where participants would only experience one environment. We were interested in replicating previous experiments which used lists of words in less complex environments, and whether we would observe a difference in memory performance solely with the presence of a doorway or not. As a result, participants were able to freely explore the space, with the only difference being the presence of a doorway or not bisecting the space.

The shimmer condition would not be tested to keep the experiment focus on the direct comparison between doorways and open spaces.

The virtual environment consisted of one large empty space, with four lists of words, with twelve words each, printed across the walls, making for forty eight words in total to learn. Otherwise, there were no other objects or stimuli in the space, and all the walls were painted a plain white. The room was either separated by a doorway, bisecting the room in half, or completely open, with only the four walls and lists of words. The composition of the lists of words and their locations were identical across both conditions. The words selected were either the name of objects in the office space (computer, desk, plant), or adjectives describing features of the objects (blue, small, round). The forced choice recognition test was changed somewhat for the list of words, where 3 words were shown, where they could be synonyms (for example; sofa, couch, & suite), or similar spellings (for example; blue, glue, & due), and participants had to choose the correct choice, as only one of the choices were present in the environment they explored. This seemed like the most appropriate measure to be able to compare with the forced choice recognition test of the first study, as participants were still presented with stimuli from the environment and had to choose from a multiple-choice question.

Figure 2.8

The Two Boundary Conditions in the List of Words Environments.



Note. Top; The “No boundary” condition with no boundary bisecting the environment, bottom; the “Doorway” condition with a doorway bisecting the environment

2.7.3 Procedure

For the procedure refer back to the procedure outlined in the general methods (section 2.2.4)

Similar to experiment one, participants had five minutes to explore the virtual environment, in which they could freely explore. There was similarly no distractor task used due to the shift between virtual reality for encoding and testing memory in the real world being deemed an appropriate disruption. The participants first completed a free recall task then completed a forced choice object recognition test.

As this experiment was focused on the immediate difference in memory performance immediately after encoding, no follow-up one week later was carried out.

2.8 Results

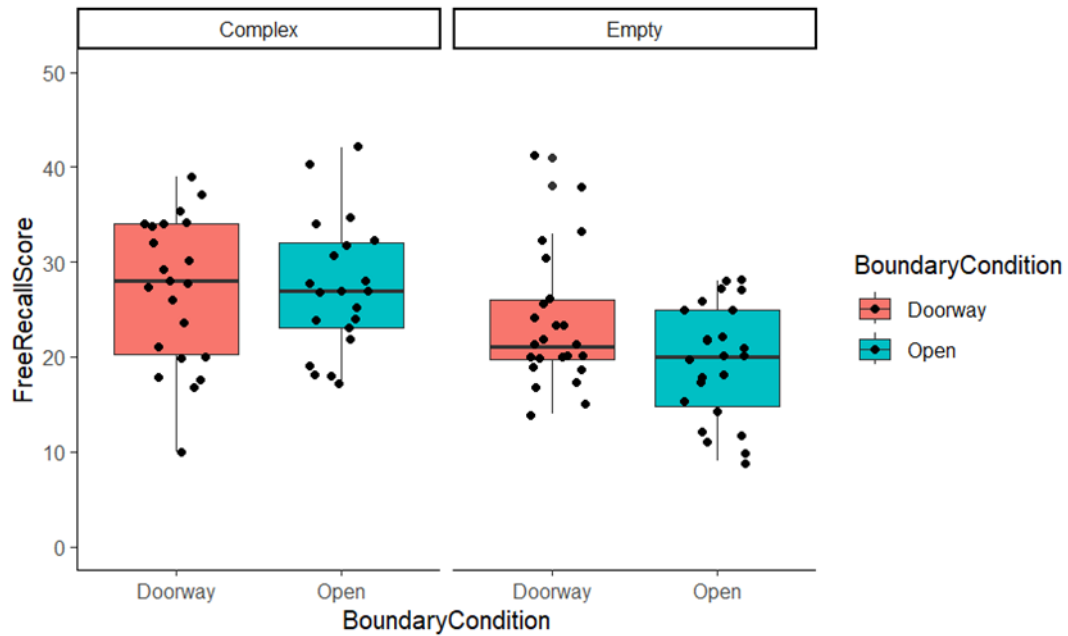
2.8.1 Free Recall of word lists

We also investigated whether the presence of a doorway in an environment would have an effect on free recall performance for the lists of words in empty rooms. An independent t-test showed that there was a significant difference in free recall scores between boundary conditions, with those in the doorway condition having higher free recall scores ($M = 23.38$, $SD = 6.84$), than those in the open condition ($M = 19.54$, $SD = 5.99$); $t(46) = 2.06$, $p = .045$, $d = .60$, $CI = .093 - 7.57$.

We then compared the free recall scores from this experiment to those of Experiment 1, using the immediate doorway and open condition scores from that experiment. We used a 2x2 ANOVA to investigate the effect of boundary condition (doorway, open space), and test environment (empty, complex) on recognition performance. Results indicated no significant effect of boundary, $F(1,87) = 1.99$, $p = .162$, $\eta_p^2 = .022$, nor a significant interaction between boundary and test environment, $F(1,87) = 1.55$, $p = .216$, $\eta_p^2 = .018$. However, a significant effect was observed with the effect of test environment, $F(1,87) = 15.65$, $p < .001$, $\eta_p^2 = .152$.

Figure 2.9

Average Free Recall Score by Boundary Condition, Comparing Performance in a Complex Environment and Empty Environment



Given the mixed results of the ANOVA, further analysis was carried out to assess the strength of the null in the boundary effect. With $BF_{01} = .444$, the null hypothesis is 2.25 times more likely than the alternative hypothesis to be true, and can be considered weak evidence that the null is true.

Due to the lists of words being made up entirely of unique words, it was not deemed to be an appropriate test to look at the unique stimulus recalled from each room. This is particularly important as it would not be a fair comparison when analysing these results with experiment 1 due to the mixture of unique objects and non-unique objects used in those spaces.

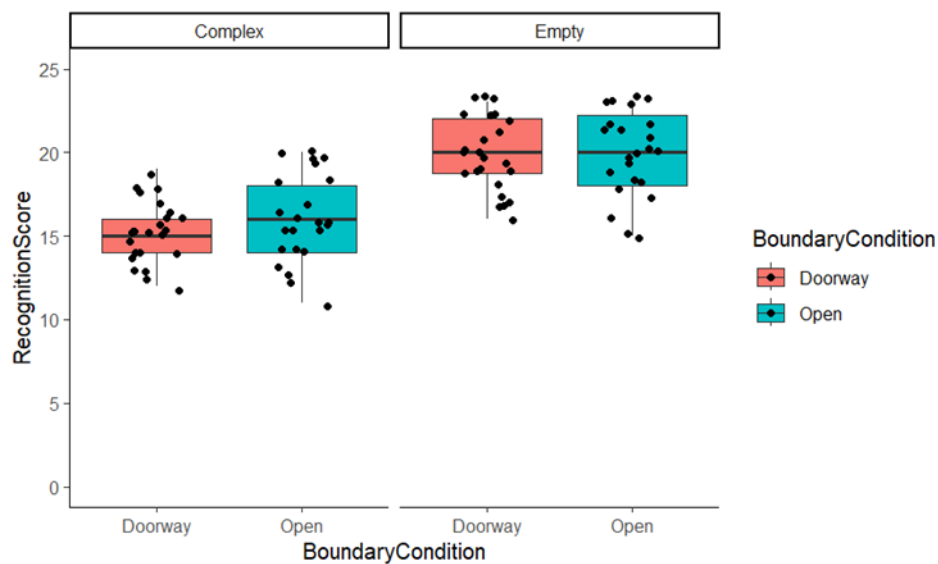
2.8.2 Forced Choice Word Recognition

We investigated whether a doorway being present in an environment or not would have an effect on performance in a forced choice recognition test when learning lists of words in empty rooms. Using an independent t-test, there was not a significant difference in participants' recognition scores tested in the environment with a doorway present ($M = 19.41$, $SD = 2.45$) and no doorway present ($M = 20.04$, $SD = 2.51$); $t(46) = -.873$, $p = .38$, $d = -.252$, $CI = -2.07 - .81$. With $BF_{10} = .294$, the null hypothesis is 3.40 times more likely than the alternative hypothesis to be true and can be considered somewhat moderate evidence that the null is true.

We compared the recognition scores from this experiment to those of Experiment 1, using the immediate doorway and open scores from that experiment. And so, we used this 2x2 ANOVA to investigate the effect of boundary condition (doorway and open space), and environment (empty or complex) on recognition performance. Results indicated no significant effect of boundary condition, $F(1,87) = 1.08$, $p = .302$, $\eta_p^2 = .012$, nor a significant interaction between boundary condition and environment, $F(1,87) = .496$, $p = .483$, $\eta_p^2 = .006$. However, a significant effect was observed for environment condition, $F(1,87) = 73.05$, $p < .001$, $\eta_p^2 = .456$.

Figure 2.10

Average Forced Choice Recognition Score by Boundary Condition, Comparing Performance in a Complex Environment and Empty Environment



Given the results of the ANOVA, further analysis was carried out to assess the strength of the null in the boundary effect. An independent t-test was also used to assess the boundary effect, with no significant difference found between those in the doorway conditions ($M = 17.63$, $SD = 3.08$), and those in the open conditions ($M = 18.18$, $SD = 3.29$); $t(89) = -.819$, $p = .415$, $d = -.172$, $CI = -1.87 - .78$. With $BF_{10} = .295$, the null hypothesis is 3.39 times more likely than the alternative hypothesis to be true and can be considered moderate evidence that the null is true.

2.9 Discussion

Looking at the results from this experiment, we do not see a strong amount of evidence to support the idea that doorways cause forgetting. But there are some significant differences between boundary conditions, which once again highlights the questions that remained open after Experiment 1. If we found significant differences in memory performance when the task was simplified to only look at lists of words, but yet not when using more complex environments, how important of a role do doorways have in dictating memory performance? The results of the present study indicate that doorways have some role in which they are able to produce a significant difference in free recall performance, but not in recognition performance.

2.9.1 Doorway effects

Doorways did not have a significant impact on recognition scores between the two boundary conditions, both when looking at the list of words environment in isolation, as well as comparing the lists of words (Experiment 2) to the more complex office (Experiment 1). Mean scores for boundary conditions were strikingly similar within each testing environment, which have some implications for the testing method and perhaps the theory of the EHM. These findings suggest that our ability to recognise stimulus and discern correct information from incorrect information is not influenced by the presence of a boundary, regardless of the format of the stimuli to be remembered (word list vs objects). While the mixed results suggest that there is some influence of event segmentation on memory performance, the exact effect remains unclear, and is not as evident as the EHM and previous research would suggest. The process of event segmentation is to divide a continuous stream of information into easily accessed and manageable chunks, so we should expect to see some differences whether the environment had a boundary bisecting the space or not.

This experiment was designed with the idea of creating a closer replication to the series of experiments by Pettijohn and Radvansky (2016; 2018). We tested whether we could find clear differences in memory performance, to reproduce the findings of these experiments. While testing conditions were closer to those of Pettijohn and Radvansky, we tested memory in a slightly different way, by including recognition, to see if any differences would be found across multiple memory tests or just recall. And with the findings of the recognition tests, it appears as though doorways do not have a strong influence our ability to

parse distractor stimuli from true stimuli, and recognition ability appears consistent across both conditions. Recognition memory relies more so on fine grain memory, being able to recognise small changes or individual components of a stimulus, and when memory performance is focused on recognition and detail, doorways do not have a strong influence on recognition performance.

This question becomes more important when we consider the results of the effect of boundaries on free recall scores, where we do see a significant difference. In the list of words environment, we see the presence of a doorway results in significantly lower free recall performance in comparison to those who were tested in an open environment. This finding was expected as it supports the findings of previous works, that “doorways cause forgetting”, and so this finding suggests that the presence of a doorway can influence memory. We see a significant finding here in comparison to the recognition results due to the difference in what these tests are assessing. Where recognition focuses on fine grain detail and the parsing of information, free recall is more so assessing associations and is open to the influence of previous knowledge and experience. Participants are able to recall the information in the order they remember and work through the space, where remembering one object may trigger another object to be remembered. Context plays an important role here, where semantic and episodic memory are integrated in a way we do not see with the recognition task. As a result of relationships and associations, it is more likely the disrupting nature of doorways can impede the encoding of stimuli, and result in a difference in free recall performance, as demonstrated by these results.

However, it is important to keep in mind that while the difference was significant, it was not a particularly strong finding. With a medium effect size and a confidence interval that comes close to 0, the effect of doorways does not appear to be as strong as previous research claims. For example, Pettijohn and Radvansky, (2016) found an effect size of $\eta_p^2 = .51$ for boundary effects, while Pettijohn and Radvansky (2018), found an effect size of $\eta_p^2 = .31$ for boundary effects. Both findings effect sizes are considered large effects by the generally accepted interpretation of η_p^2 using Cohen’s guidelines (Cohen, 1988). The strength of this effect is called further into question when we include the comparison with Experiment 1, where a significant effect of boundaries is no longer present. While there is an argument for doorways

affecting memory performance, it appears as though the conditions under which this effect emerges is specific, and when we try to find the same effect in closer to real world environments, the effect is no longer present. This calls into question the findings of previous work, where researchers could have considered the role of the environment being tested in earlier to have a clearer understanding on the role of event boundaries on memory, because currently, the claim of “doorways cause forgetting” does not appear to have real world applicability based on the presented data.

2.9.2 Testing environment effects

The environment in which participants were tested in, being whether it was an empty room using lists of words, or a complex office space using objects, produced large significant differences in memory performance, both in recognition and free recall tasks. In terms of the recognition task, those in the empty environment performed significantly better than those in the complex environment. Conversely, those in the complex environment performed significantly better in the free recall task than those in the empty environments. The memory performance in both tests using empty spaces and lists of words is different than using complex environments and objects. It should be expected that we would find such strong differences between these testing environments as exploring a complex environment is a much different task from learning lists of words. However, when these findings become a concern is when we acknowledge the theoretical implications of this work.

One explanation for the converse effects is the role of context, and how it interacts with the kinds of test which are being used. For free recall, association can be used to make causal relationships between objects, and the context of a complex environment makes this an easier process in comparison to the empty environment. In the complex environment, we have expectations of what we would see in an office and have past experience in those spaces, so can apply pre established schemas to the retrieval process. However, in an abstracted environment, such as the list of words space, previous knowledge and experience plays less of a role on retrieval, and so, memory performance will be much more reliant on working memory and mnemonics, which have an upper limit. Conversely, the role of context and experience may make recognition for objects more difficult in comparison to an abstract list of words. As we changed orientations, sizes and colours, interference can play a larger role, where participants would have to parse out potential information they could have seen in

the past or in similar environments. The lists of words however, will hold less associated knowledge and experiences which would be likely to interfere with the recognition process, and so, recognition of stimulus can be done more efficiently than in the complex environment conditions.

The EHM was proposed with the intention of explaining how we segment experience into easily accessible chunks which can be recalled at a later point. A lot of the focus of this model is on relationships between segments and environments, as well as what objects make up an event. However, a majority of the research which then goes on to support the EHM use methods similar to this experiment, testing in simplified environments with lists of stimuli, and then go on to make claims about how we process real-world environments and the effects segmenting can have on memory for a space, namely the claim that “doorways cause forgetting”. However, as highlighted with the comparison between this experiment and Experiment 1 is that these scenarios and experiences are not really comparable. Significant effects of boundaries on memory performance are dependent on the medium they are testing, where boundaries have a significant effect testing lists of words, where the effect is not significant in complex environments. This medium effect is due to the role of context and previous knowledge, in a complex environment, objects are in an embedded context, and we will have previous experience engaging with similar spaces and objects. However, with a list of words, the abstracted nature of the information means that this associative memory plays less of a role, and context does not have the influence it does in complex environments. Due to the differences in expectations and previous experience between these two mediums, how the information is presented has a large role to play in the impact of boundary effects.

These findings highlight a point previously made where we must take stronger consideration of ecological validity and how generalisable findings are to real world processing. With free recall being significantly worse and recognition significantly better in the list of words environments, regardless of the presence of a doorway or not, it raises the question. Do doorways cause forgetting? It appears so when we test in empty environments using lists of words, however, when we test in more complex and real to life environments, given that we are seeing strong differences in free recall and recognition ability in both directions depending on the task, it is unclear to what extent we can apply those findings to real world scenarios.

While different stimuli was used between both experiments, comparing the results of the recognition test was still deemed to be an apt comparison. This is due to the nature of the test focusing on one component of the environment, whether one object or one word, and parsing it out from noise, whether that be choosing the correct location for an object, or the correct word from a list of words sharing the same meaning. So while the stimuli was different, the tasks utilised similar skills, and the number of and structure of the test was the same. As a result of how we tested recognition, the comparison was judged to be a fair assessment of recognition ability across environments.

One limitation of the List of Words testing is that we did not look at the proportion of words learned from each of the rooms. In experiment one, we looked at the proportion of unique objects that were recalled from each space, and used this measure to support the differences in coding across a doorway. However, in experiment two, all the words were unique and so, comparing room performance to the first experiment was deemed inappropriate as scores would be artificially inflated with no repeating stimulus in the List of Words experiment. In future, the proportions of words recalled from each room would still be valuable information and should have been calculated to support the claims of boundary effects.

2.10 Conclusion

From the two experiments of this study, we can conclude that the role of boundaries in environments cannot be reduced to a single effect. The findings suggest that event boundaries have some effect on how we process a visual scene, but a doorway being present in a room alone is not enough to produce strong differences in memory performance. It remains unclear what influence doorways have on memory, however, it is clear the effect of event boundaries on memory is not a single effect. To claim that doorways cause forgetting is an oversimplification as to how we explore and interact with spaces. There are two potential conclusions to draw from the results of these two experiments. One is that the role of doorways is minimal and only affects a specific facet of memory under controlled conditions, and two is that we do not understand the extent to which event boundaries affect how we process a scene, to which follow-up research is needed to understand event boundaries and the process of event segmentation more thoroughly. Memory performance in the current

experiments was influenced by the nature of the memory task, the presentation of the learning environment and the to be remembered stimuli, and when the tests were being administered.

Moving forward, a more multifaceted approach is needed if we want to understand the process of event segmentation and the role event boundaries play in that process. Some ideas to be further explored are the context of the scene, the purpose of the event, as well as the relationship between different objects within a given event. How we process information in daily life is an extremely complicated process, and as a result, we much approach research into the event segmentation process with an awareness of that complexity. Moving forward, research should be mindful of why we are segmenting at a specific point, how do we segment information, the function and presentation of a given scene, and what we are being asked to do throughout a single event.

Following up this work will be a focus on expanding our ideas of event segmentation, to not only look at the effect of doorways but also what spaces those doorways are segmenting. The current study highlighted methodological issues with the current body of research surrounding the EHM and raising questions about the ecological validity of that body of work. The next stage will move beyond the EHM and take a more explorative approach to event segmentation, to explore what conditions we can generate more explicit memory differences in, while adopting a more holistic perspective on the process of event segmentation.

**Chapter 3 -
Moving beyond doorways and forgetting: Reframing our ideas**

Chapter 3 – Moving beyond doorways and forgetting: Reframing our ideas

3.1 Introduction

Following up on the results from Chapter Two, it is clear that our understanding of event segmentation is not as comprehensive as research surrounding the EHM and doorways claim. The mixed findings of the previous chapter suggest that there is not just one single effect of boundaries on memory, with results being influenced by the task, the type of objects being recalled, the period of time elapsed between exploration and recall, and so on. Moving forward, it is important to think of what could lead to variations in the effect of doorways, and under what circumstances do we observe consistent positive or negative effects. This leads to questions centred around what is the purpose of segmenting spaces, how do we traverse between different spaces, and what is the importance of the presentation and function of the spaces themselves? Focusing on why we move between spaces and what spaces we are moving between, as well as what it means to be a spatial event boundary and how can we change spatial event boundaries to draw out different memory effects, and less so on whether there is a doorway present, is a necessary consideration in further developing the EHM, while making the model clearer on when we should expect influences on recall, and whether these influences are positive or negative.

3.1.1 The Process of Segmenting Events

The process of organising a stream of consciousness into meaningful events, known as event segmentation, is a fundamental cognitive process which shapes perception (Shipley & Zacks, 2008), actions (Schubotz et al., 2012), and memory (Shin & DuBrow, 2021). There is a large amount of regularity and agreement for when events begin and end when observing a sequence, irrespective of the participants having prior knowledge of the event or whether they fully understand what a meaningful event means (Levine et al., 2017; Newberry et al., 2021). This level of consistency stretches from large grain divisions, such as overarching tasks, to fine grain, smaller details, such as individual actions within a task. We even see agreement between age groups when we look at the difference between adults and children, where there were no systematic differences between the two groups when segmenting a non-verbal children's animation show (Pingu; Zheng et al., 2020). These findings highlight the intuitiveness and ease at which we segment information.

While it is important to understand when a spatial event boundary is created, the process of creating spatial event boundaries is much more consistent than the process of recalling the content of an event. Between event boundaries, the events themselves comprise individual components such as the objects in a room, or individual behaviours which make up a routine, which are processed differently from the holistic view of an event (Magliano et al., 2014). While information is stored and compartmentalised across events, recognition for information is more componential than grouped together. For example, if we were to look in a scene space (e.g., a living room) and were asked to remember the individual objects within it, that is a much more difficult task than being shown an individual object, such as a chair, and being asked what scene or context we had seen it before. Event segmentation helps us make sense of the world and organise memory, but not all information is treated the same, as if every object or component was given the same level of processing as a holistic experience, it would become overwhelming to make sense of any information. With this idea of different levels of information being processed differently, there has been the development of event models (Zacks, 2020). Event models refer to immediately accessible representations of an event, and the structure of these models establish a spatiotemporal framework for the location of objects in an event, but also objects' relationships to each other and how these relationships may change with new information. With the overall scene, new objects may be introduced, and with the individual objects, they may be presented in new locations or orientations.

While segmenting information can affect memory and recall, it is not the sole purpose of this process. Event models highlight how the process of event segmentation is future orientated and predictive, where the process includes the making of predictions about what comes next based on changes to an object, environment, or goals (Zacks, 2020). This prediction allows for our behaviours to be guided in anticipation. To be able to predict efficiently, we develop event models, which act as a schema for what we should expect to occur in a given event. In order to ensure these schemas are updated, they rely on past experiences and context, meaning that despite being a forward orientated process, event segmentation is heavily reliant on past information. Segmentation then structures and organises our memory of past events, it creates a cycle, where segmentation facilitated structuring our conscious experience with the previous information which was organised and processed using that process already.

Understanding the process of how we segment events is fundamental if we are to understand the effect of event segmentation on memory. A lot of variables inform when segmentations occur, including expectations (Metcalf & Leake, 2017), prior knowledge (Newberry & Bailey, 2019), and changes to an object, environment, or goal (Swallow et al., 2018). With the process of segmentation being so complex, there is a need to approach research into the process with this complexity in mind. To not only think about whether a boundary is present, but what function does the boundary serve, what are the characteristics of the boundary, and how do we move through the boundary. Similarly, what functions do environments serve, how do we move around the environments, and what are the visual characteristics of the environment.

With that in mind, Experiment 3 explores environments as events: how changing the aesthetics of an environment while retaining the same layout affect memory performance. Experiment 4 then explores the nature of event boundaries, specifically whether all event boundaries are treated the same. While previous boundary research has focused on forgetting (Pettijohn & Radvansky, 2016; 2018), the current chapters will focus more so on the nature of segmenting and the importance of the spaces we are in and moving between.

3.2 Experiment 3- Introduction

As previously discussed, the idea of competitive and non-competitive stimuli is very important to the EHM. This idea dictates whether recall will be benefited or hindered through the segmentation process. However, the concept of competitive stimuli remains underdeveloped, resulting in questions such as how similar or different do objects or spaces need to be to be considered competitive or not. And with this underdeveloped concept, the effect of competition is also unclear, for example, do similar stimuli overlap in encoding processes making it easier to confuse or misremember some objects, or do very different objects disrupt encoding. As theorised by Wang et al. (2024), internal determinants such as affective states and goal states have an effect on our ability to segment, however, are influenced by shifts in environmental context. When these shifts in environmental context are extreme enough, such as moving between a large social space to a smaller, more intimate room, they may result in internal determinants being influenced, and result in stimuli not being fully encoded to memory. To move forward with event segmentation research, it is important to clarify these points and we must consider previous research into how we

remember groups of objects, and how we perceive and categorise objects into separate groups, as they may help with our understanding of how breaking up events with discreet segments may influence memory.

3.2.1 Chunking and memory

Does event segmentation aid in the chunking or grouping of information or do they disrupt encoding when crossing through an event boundary? This question depends on the information being remembered; however, if we look into different mediums where information is presented, we see despite different purposes of event boundaries, information is still segmented and structured in a way that aids in recall. For example, text may be segmented by paragraphs to aid in the flow of prose, while maintaining the same location and event in the narrative of the story, while a movie may be segmented through a change of scene, cutting to new characters or perspectives. With regards to movie editing, research by Garsoffky et al. (2007), found that when viewing a contained event (a basketball game), cuts throughout the event produced lower recognition ability when asking participants to identify stills from the video, as opposed to viewing the game from a single, unvaried viewpoint. Editing can also alter our perception of event boundaries as well as memory for information within an event. Magliano and Zacks (2011), found that the strongest event boundaries were generated when a cut in a movie generated a discontinuity in action, as opposed to temporal and spatial discontinuities, or no discontinuities at all. These findings highlight the influence editing can have on the maintaining and violation of event models, and so, the editing of a movie provides structure and aids in the understanding of a sequence. While the primary function of segmenting in these instances is for story telling purposes, it does have the effect of making the story easier to remember, creating individual memorable events that make it easier for the audience to follow and remember (Gold et al., 2017). Even if a scene does not have a unique narrative purpose, such as watching a movie of someone completing a morning routine, the cuts in the scene still structure the sequence making it easier to learn and recall. Through the chunking together of information, a sequence of events or a number of objects can be recalled better when part of a distinct event.

Segmenting events can aid in memory, as suggested by Flores et al. (2017), who found that patients watching movies of naturalistic activity had superior memory of the movie when asked to press a button to segment the movie, instead of only watching and

trying to remember. These findings were supported by Smith et al. (2024), who similarly found a superior memory performance when participants were asked to focus on the segments of a video, with a substantial effect observed in young adults. These studies suggest that focusing on dividing events and chunking sequences together while attuning to the segments has a positive effect on memory.

However, the function of a physical space is not to convey a linear narrative or to focus on one idea or thought at a time, like text or film. We have experience with real world spaces, associations with similar spaces, and where movies and stories present information to serve a narrative or story, in real life, objects and space do not serve a single function; instead, they are there to be interacted with by multiple people at different times. On top of that, moving between scenes in a book or movie often includes a change in time or place, whereas real-world perception is continuous. While spaces may be different, thoughts, gaze or movements continue and carry through the boundary. In continuous experience, does a new space contain too much new sensory information to efficiently process? If so, would crossing through event boundaries into new spaces disrupt encoding, resulting in it not being possible to neatly group information together within event boundaries?

One important consideration in this conversation is how space can shape and organise memory. Aronowitz and Nadel (2023), make the argument that episodic memories are categorised by space, where we can recall multiple memories within a space that are not constrained to a timeframe, meanwhile, recalling a specific timeframe is very limiting, and still likely to be shaped by space. In this example, spatial event boundaries play an incredibly important role where the walls and boundaries of a space are holding your memories of that space, and so, while individual events may not be constrained to a single space, many aspects of memory are contained within those spatial event boundaries. In this case, spatial event boundaries do not contain individual event memories as a whole, especially as you may move between rooms within a given event. However, they hold information of many different events and shape how that information is encoded, stored and recalled, and chunking may be a function of how space shapes memory.

If it is the case that moving between new spaces can cause a disruption in the processing of events, as suggested by Wang et al. (2024), or that spatial event boundaries can hold information of many different events, how big of a role do competitive stimuli play in this? If environments were similar to each other, would the number of distinct objects be low

enough that it would not be as disruptive to continuous cognitive processes, whereas very different spaces may overwhelm an individual moving between them with more unique information. Alternatively, do very different spaces create a distinct event boundary which makes it very easy to delineate between the two spaces, where similar spaces do not create as distinct an event boundary, thus potentially trying to fit too much information into a single event? Due to the lack of clarity that has resulted from research focusing more so on the event boundary and less so on the spaces being segmented, it is important to consider what a competitive space is and what role these competitive spaces play in memory performance.

3.2.2 What is a competitive space?

In the EHM, competitive and non-competitive stimuli are posited to effect whether event segmentation will benefit or impair recall. However, a clear definition is not given to what is considered competitive or not. There are multiple possible interpretations for what could be considered competitive stimuli, for example, seeing the same object in multiple locations, or objects that share similar characteristics, such as aesthetic, function, or even as simple as size and shape. Franconeri et al. (2013) argue that our representations of space are presented in a cortical map, where individual objects compete for space on the map. Objects are delineated by features like spatial location, colour or shape. However, they also consider that similar objects can overlap and be clustered together, resulting in two forms of competition: i) inter-item competition, where there is significant overlap between individual items, which then suppresses the ability to accurately recall individual items, for example, if you were trying to remember the location of an individual book at a library, the number of books and similar layout would make it difficult to recall a single book's location. ii) extra-item competition, where two entirely distinct items are competing for individual space on the cortical map, for example, being in a clothes store may make it more difficult to remember where objects were in a food store due to the distinct products and layout of those spaces. These definitions are considered flexible, suggesting why it is possible for some situations to result in superior recall, and others inferior. With how complex environments can be and the complexities of perception, it is unlikely that one approach is going to apply to every environment we interact with. However, the suggestion of flexibility does not help us in understanding in which circumstances objects are considered competitive or not.

And with this discussion on competitive spaces, once again, the role of spatial event boundaries come into question. Is it that the spaces themselves are causing the differences in memory performance through interference, or does the presence of a spatial event boundary provide a clear delineation between rooms that may emphasise or minimise these ideas of competition. Montello (2007), discusses how physical environments can affect a number of psychological mechanisms and highlights sensory access, attention, behavioural affordance and memorability. Within these psychological mechanisms, spatial event boundaries provide a framework for the spaces, allowing discreet yet interconnected spaces to emerge. With competitive spaces in mind, spatial event boundaries may be crucial for the flow and accessibility of both of these spaces, both in terms of movement, and encoding and recall. And so, we would expect any spatial event boundary related memory effects to emerge more so between distinct spaces, where the spatial event boundary serve a crucial role of separating distinct spaces with their own aesthetics and function. More attention will be drawn to the spatial event boundary and competition may be a function of the more or less prominent spatial event boundaries.

3.2.3 Aims and objectives

The primary aim of this experiment was to determine whether memory performance for a set of objects was better when two spaces are aesthetically similar or distinct from each other. Based on the original principles of the EHM, we would expect objects presented in aesthetically distinct contexts to show superior recall, as they would not be considered competitive stimuli within the one environment (Franconeri et al., 2013). A clear delineation of two distinct spaces may be easier to not confuse, aiding chunking in memory, as opposed to the similar spaces where there is less distinctions delineating the two spaces aesthetically. In contrast, participants may find it easier to remember objects in similar spaces as there would be less competition (Johansson & Johansson, 2020) on the cortical map due to the similarity of the context of the objects.

Based on previous work on the topic, it was hypothesised that there would be a significant difference in memory performance for a common set of objects between aesthetically similar and different conditions, with aesthetically different conditions producing better performance than the aesthetically similar condition.

3.3 Methods

3.3.1 Participants

Participants consisted of psychology 48 undergraduate students, with a mean age of 20.15 (SD = 3.51), made up of 35 female, 11 male, and 2 non-binary participants. These participants were recruited using the University of East Anglia's School of Psychology Research Participation Scheme. Participants were offered two course credits for completion of the study. Participants were randomly allocated to each variable, with no demographic variables being used for group allocation.

A power analysis was conducted using the effect sizes from Lawrence & Peterson (2016), due to the comparison of only two groups and the use of t tests in this research topic. Based on their reported effect sizes, using g*power, it was determined an acceptable n would be 81 for an appropriately powered study. It was important to the researchers to maintain a similar n per condition throughout the first four experiments due to the same paradigm being used and for these follow up experiments acting as modifications on the original. As a result, the n of the following experiment was 48 to match the same condition numbers as the previous two experiments.

To assess power more thoroughly, a post hoc power analysis was conducted to assess the achieved power of the study. With an n of 48 and an effect size of .652, the achieved power of this study was .72, meaning the results of this study are slightly underpowered in comparison to the standard of .8

3.3.2 Design

As outlined in the general methods in the previous chapter (Chapter 2.2.2), the experiment used a between participants design. The experiment consisted of two parts: in part one, participants explored a VR environment consisting of two rooms; in part two, participants completed two memory tests including a free recall and forced choice recognition

tests. Free recall was scored by asking participants to list all the objects they remember seeing in a space and for each object listed that was present in the space, one point was given. The independent variable was whether the rooms were similar or different in their aesthetics; the dependent variables were performances on the free recall and forced choice object recognition tests.

Participants would explore the virtual environment for five minutes, however, they were given the option to come out of the environment early if they felt they were ready to complete the memory tests, or needed a break from VR. Similarly, the memory tests were conducted immediately upon coming out of the VR environment, with the opportunity for a short break if they were feeling sick or disorientated, however, this break in the experiment was not mandatory.

3.3.3 Materials and Apparatus

The virtual environment consisted of two small rooms in the form of either two office spaces (Figure 3.1a), or an office space and a space station (Figure 3.1b), and in both conditions, these spaces were separated with a doorway, developed in Unity. These spaces were filled with objects that had to be remembered. Both adjoining rooms in both scenes were matched for objects, so where there was a laptop or tv in the office space, an equivalent would be present in the space station, just aesthetically different. The starting office spaces were identical between conditions, and the second room shared identical layouts. The only difference was the aesthetic appearance of objects and walls, as well as the external skybox, either consisting of a blue sky and green field for the office condition, or a galaxy in space for the space station condition.

The identical first room across conditions allowed for a comparison point between the two conditions, as no matter which condition the participant was allocated to, they began in the same space. The purpose of matching layout and object function in the second room was to draw out memory differences resulting from the aesthetic differences across spaces. With this approach, any differences in memory performance could be pinpointed to the aesthetic differences of the space, as opposed to differences in objects or special layouts.

Figure 3.1a

The two office spaces in the aesthetically similar condition

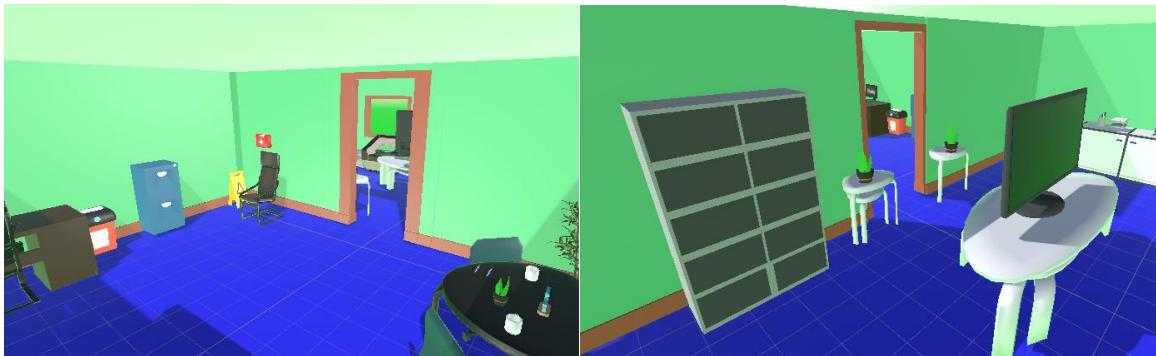


Figure 3.1b

The office space and space station in the distinct condition



A change from the first study was moving from Qualtrics to Gorilla Experiment Builder to create and run the memory tasks. Gorilla was used for all experiments moving forward in the project. However, the format and structure of the questions remained the same as the first experiment, which can be found in the general methods (Chapter 2.2.5).

3.3.4 Procedure

The procedure was the same as before except with the following amendments. As there were visual differences between the two aesthetic conditions, test items in the forced choice recognition test were matched so the questions would be looking at the same objects in the same locations, and the questions were presented in the same order for both conditions, just with the aesthetic differences of the condition. For example, if the question asked about the orientation of an object for the similar rooms condition, the same question would be asked about the equivalent object for the different rooms condition, and the changes to the objects would also be consistent, so the two foils would be orientated in the same way. This consistency in the foils was to ensure comparisons between conditions would be fair and appropriate, and to match the other experiments from chapter two, using the forced choice recognition test as close as possible.

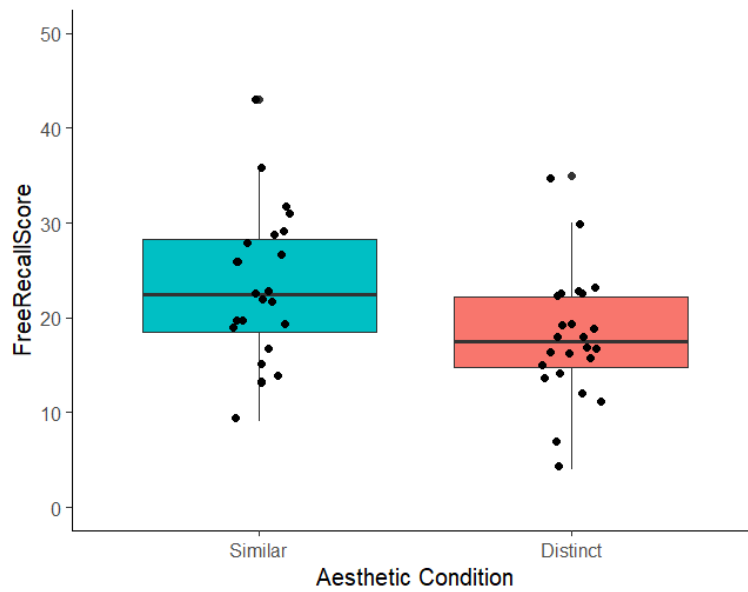
3.4 Results

3.4.1 Performance on the Free Recall Memory Task

An independent t-test showed that there was a significant difference in free recall scores between the aesthetic conditions. Participants correctly recalled a greater number of objects when they were presented in aesthetically similar room ($M = 23.17$, $SD = 8.01$), compared to those in the aesthetically distinct rooms ($M = 17.96$, $SD = 6.62$); $t(46) = 2.46$, $p = .018$, $d = .71$, $CI = .94 - 9.48$.

Figure 3.2

Average Free Recall Score by Room Condition, Comparing Similar and Distinct Environments

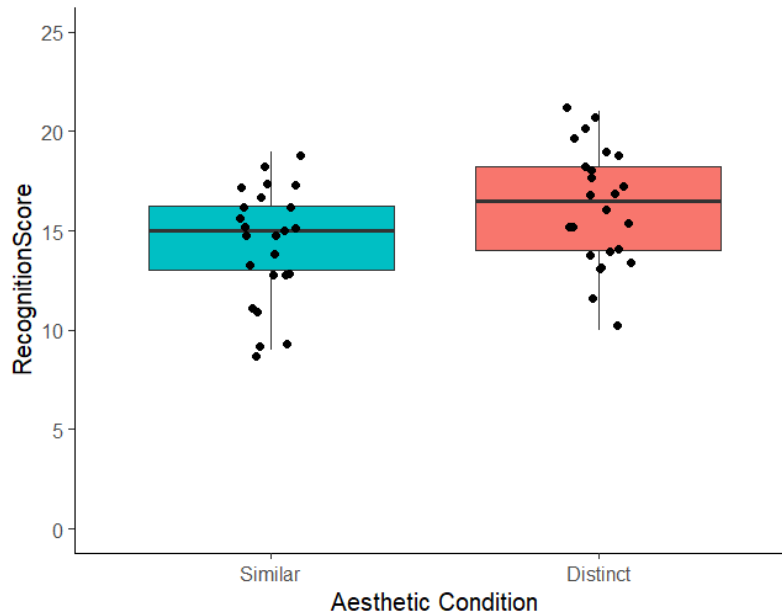


3.4.2 Performance on Forced Choice Recognition Task

An independent t-test indicated that there was a significant difference in recognition scores between the aesthetic conditions. Those tested for their memory of the objects in the aesthetically similar rooms performed significantly worse ($M = 14.29$, $SD = 2.87$) than those tested in the aesthetically distinct rooms ($M = 16.21$, $SD = 3.01$); $t(46) = -2.26$, $p = .029$, $d = -.652$, $CI = -3.62 - -0.21$.

Figure 3.3

Average Forced Choice Recognition Score by Room Condition, Comparing Similar and Distinct Environments



Note. Maximum score was 25

3.4.3 Performance on Memory for Unique Objects Proportionally per Room

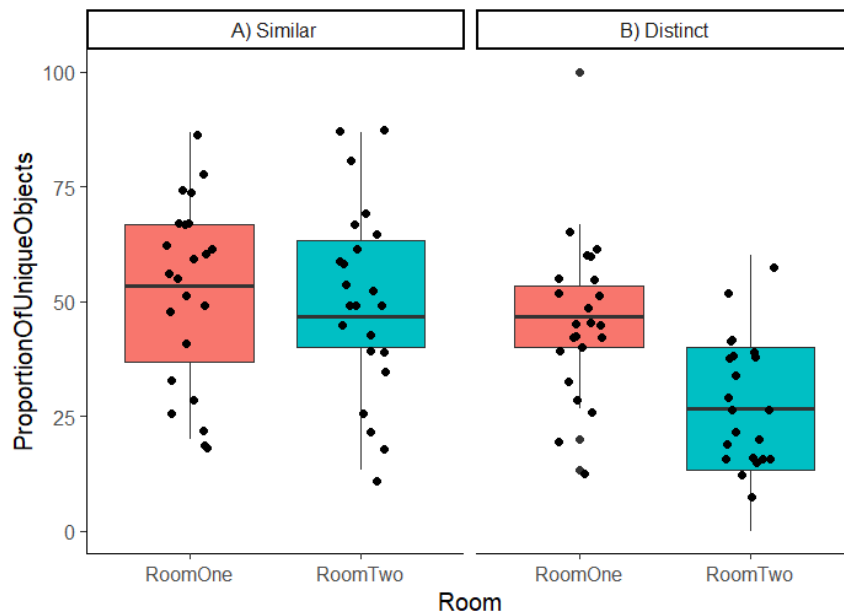
Using a 2x2 mixed design ANOVA, we investigated the effect of room aesthetics (similar and distinct) on free recall memory for unique objects across each half of the environment, where the starting room was Room 1 and the adjoining room was Room 2, with this effect being the effect of test room (starting and adjoining). Unique objects were explored to examine whether participants were learning the two halves of the environment as individual spaces, or learning more general objects that were present in both halves of the overall environment. They were also examined to determine if there was a bias towards learning one half of the environment over the other. There were 12 unique objects to remember per room, making for 24 unique objects in the total environment. Results indicated that those in the similar rooms condition recalled a significantly higher proportion of unique objects ($M = 51.16\%$, $SD = 19.88\%$) than those in the aesthetically distinct rooms condition ($M = 36.52\%$, $SD = 19.26\%$); $F(1,44) = 19.54$, $p < .001$, $\eta_p^2 = .308$. The pattern of results is similar to those found in the overall free recall performance. A significant main effect of test room was also found with differences between the starting and adjoining rooms, where a higher proportion of unique objects were recalled from the starting room ($M = 49.13\%$, $SD = 18.87\%$), than were recalled from the adjoining room ($M = 38.55\%$, $SD = 21.49\%$); $F(1,44) =$

8.96, $p = .004$, $\eta_p^2 = .169$. Finally, a significant interaction was found, $F(1,44) = 14.55$, $p < .001$, $\eta_p^2 = .249$.

As an interaction was found between room aesthetic and which half of the environment unique objects were being recalled from, two further t-tests were carried out to establish the interaction effect. The first t-test found that there was no significant difference in the proportions of objects recalled from either half of the environment when participants were in the similar aesthetic condition, where Room 1 ($M = 51.88\%$, $SD = 19.89\%$), Room 2 ($M = 50.44\%$, $SD = 20.28\%$) showed similar levels of proportions of unique objects recalled; $t(44) = 0.245$, $p = 0.808$, $d = 0.07$, $CI = -10.49 - 13.39$. However, there was a difference in the proportion of unique objects recalled between rooms when the rooms were aesthetically different, where a significantly higher proportion of unique objects were recalled from Room 1 ($M = 46.38\%$, $SD = 17.82\%$), than from Room 2 ($M = 26.67\%$, $SD = 15.44\%$); $t(44) = 4.01$, $p < 0.001$, $d = 0.55$, $CI = 9.81 - 29.62$.

Figure 3.4

Relative Proportion of Unique Objects Recalled in each Room by Aesthetic Condition



3.5 Discussion

3.5.1 Overview of Results

In the current experiment, we observed significant differences to recognition and free recall scores between whether participants explored two aesthetically similar or distinct rooms. However, a consistent effect was not found, with those in the aesthetically similar condition performing better in the free recall task, yet those in the aesthetically distinct condition performing better in the recognition test. These results highlight the complexity of competition in relation to memory, where dependent on task, different effects are observed. The effect of competition becomes further complex when we look at the percentage of unique objects remembered, where those in the aesthetically similar condition recalled a higher proportion of unique objects in comparison to those in the distinct condition. On top of this main effect, there was an interaction between room and condition, where those in the aesthetically different condition saw significant differences between the room they were recalling stimulus from, where those in the similar condition did not. From the results of the current experiment, it is clear the distinctiveness/similarity of spaces has an important role to play in the ability of participants to recall stimuli. However, the multidirectional nature of the results indicate that it is not as simple as a single effect of stimuli competitiveness, but perhaps multiple effects of competition interplaying. As a result of these complex findings, a nuanced discussion is required looking at each of the results in isolation to understand what effects may be taking place.

A pattern emerged in this study where we saw opposite results with which condition performed better in which test. One explanation for this result may be the role of parsing information in the recognition tests as opposed to the free association of the free recall task. In the recognition task, interference may play a larger role in the encoding process due to participants needing to recall specific details in order to make the correct choices. Here the competition of similar environments would cause higher interference in the encoding of the environments in comparison to the distinct spaces. However, with the free recall task, more generic information is being recalled in that they were asked to recall objects they saw, and they could recall and order that list how they saw fit. Here the repetition of the similar environments may be reinforcing the memory for the space more generally in a way that

would not be experienced in the distinct spaces, thus improving free recall performance for the similar environments.

3.5.2 Recognition

Results showed that there was a significant difference in recognition scores between the two aesthetic conditions, with those in the Distinct condition performing significantly better in the test than those in the Similar condition. This suggests that when trying to discern detail about a given space or object, this task is easier when objects are presented in two aesthetically different spaces than similar. These results fall in line with some previous literature and ideas previously discussed.

The first and, perhaps, more significant point is the role of competitive and non-competitive stimuli. In the similar condition, the features of objects being presented in a similar room context may not have been distinct enough to parse out more fine grain detail about individual objects, such as orientation, colour and location. Franconeri et al. (2013) emphasised the similarity between objects in terms of these characteristics, where memory for objects was hindered when objects were not distinct enough. Perhaps we are seeing a larger emphasis on inter-item competition, where similar objects are competing for an individual space on the map. If this is the case, it stands to reason that it becomes more difficult to recognise smaller details about an object, as it is more likely to be confused for a similar object. This idea is supported by the same effect not being found in the free recall results, where there is less of a focus on individual details, and more focus on objects in the larger space as a whole. The recognition task relied on the parsing of more fine-grained detail, and so, when there is a focus on distinguishing small details, we see a stronger influence of inter-item competition. Conversely, when the focus of the task is more so on the objects as a whole and less details about individual objects, as is in the free recall task, inter-item competition plays less of a role.

In the current experiment we see aesthetically similar environments interfering with participants ability to recognise stimuli in the environment. On the other hand, the aesthetically distinct environments are being processed as non-competitive environments, and so participants have an easier time recognising individual objects and correctly parsing out correct stimulus from incorrect representations. Again, considering the approach proposed by

Franconeri et al. (2013), where there is very little overlap between similarities of objects, they do not overlap on the cortical map and take up more space, making it more difficult to remember a large amount of information. We would expect some level of extra-item competition in this condition due to the very distinct aesthetics between the two spaces, thus objects would be competing for more distinct spaces on the cortical map; however, this competition does not appear to be as significant or detrimental for recognition ability and differentiating between correct and incorrect stimulus.

If we consider these results as a product of competitive and non-competitive stimuli then they further highlight an issue with the level of ambiguity in the EHM and its approach to competitive stimuli. Perhaps the significant difference in recognition performance is due to competition where the competitiveness of the space affects event segmentation, in turn, affecting how objects are processed, grouped together, and remembered. With competition having a significant effect on memory performance, the idea of competition needs to be clearly defined and operationalised within the model as opposed to currently, where it is ambiguous. While the findings of this experiment may support what the EHM says about competitive and non-competitive stimuli, it is difficult to make that claim due to a lack of clarity of what the EHM considers competition. While there is an aesthetic difference in the environment the stimuli were presented in, in terms of dimensions and layout the spaces were otherwise the same across conditions. The objects themselves were the same size and orientation, with just some being aesthetically different to fit the environment (e.g., a desk in the office in comparison to a table that fits the space station aesthetic). If competition is this influential on memory performance, what makes stimuli competitive or not needs to be clarified.

However, perhaps the difference in memory performance has less to do with the competitiveness of the stimuli and more so with the strength of the segmentation. In this experiment, the aesthetically different rooms would have highlighted for participants that these rooms were two discrete spaces and thus, would be processed as such. However, in the aesthetically similar conditions, perhaps the two rooms were just seen as extensions of the one space and not being regarded as two discrete spaces with an event boundary bisecting the space. As we saw in Experiment 1 (Chapter 2), a doorway alone does not produce a significant difference in memory performance and so, perhaps any effects of event segmentation were being minimised in this condition or emphasised in the distinct condition.

As suggested by Flores et al. (2017), and supported by Smith et al. (2024), attuning to an event boundary can result in superior memory performance, and perhaps this is the effect we are seeing here. Participants may have been more attuned to the event boundary and aware of its function in the distinct condition due to the doorway dividing two discrete spaces and thus participants would be more aware of traversing from one event to another. In comparison, the doorway may not be as strong a boundary when bisecting one space in the aesthetically similar condition, and participants may have been less influenced by traversing between spaces as the spaces being divided by the doorway are less discrete.

3.5.3 Free Recall

In direct contrast to the recognition results, the free recall task showed that aesthetically similar condition produced significantly higher free recall scores than those in the aesthetically distinct condition. This discrepancy between the findings across tasks was unexpected, if we were seeing competition-based interference in the first task, why do we not see the same effect in this task? Perhaps what we are seeing here is that separately processed discrete spaces can help with memory for individual components and remembering details; however, when trying to remember an overall space, the separation of spaces makes it more difficult to have an overall map of the space. On the other hand, the similar spaces may make it easier to draw associations between objects across both rooms, making it easier to recall groups or clusters with ease. The lack of competition for individual space on the cortical map and overlap with similar objects means that while it may be more difficult to recall details about individual objects, it is easier to remember more of the environment.

The opposite effect being found for the free recall task, where aesthetically similar environments produce better memory performance, may be an example of the extra-item competition as outlined by Franconeri et al. (2013). In the free recall results we can see that distinct stimuli were more detrimental to recall, whereas the aesthetically similar condition produced better performance, suggesting that inter-item competition was not as influential or important in this type of task. While the EHM can account for contradicting results, it does not offer a comprehensive enough explanation of competition, leaving one of its core concepts ambiguous. In this experiment, the only thing that changed was the memory task, it was still the same stimuli and environments being recalled, and yet the type of memory that was invoked resulted in a change in the effects of competition. If competition can have both

positive and negative effects depending on the nature of memory retrieval and the stimulus being remembered, it is important for the model to provide a clear idea of when we would expect to see positive or negative effects on memory performance.

However, similar to the recognition results, the results of this free recall task may yet again be explained by the strength of the segmentation, and less by the competitiveness of the stimulus. Zacks (2020) has made the argument that walking through doorways causes a temporary disruption to encoding which could affect memory recall and this could be the effect we are seeing here. As previously discussed, the event boundary appears to be more evident in the distinct rooms condition than in the similar rooms condition, and if participants in the distinct condition are experiencing more disruptions to encoding, it would result in worse free recall performance. Research supports this idea of an encoding disruption, Wang, et al. (2023), found that memory performance was impaired not only after passing through a doorway, but also just before crossing the doorway, suggesting the anticipation of an event boundary caused a disruption to encoding.

The differences in the free recall performance are highlighted further with the pattern of unique objects recalled, where overall, those in the similar environments recalled more unique objects across both rooms in comparison to those in the distinct condition. However, there was also an interaction with differences between aesthetic conditions and the bias towards one room over the other. Those in the similar condition appear to have better memory for the overall environments and are able to recall stimulus within the environment with more accuracy than those in the distinct condition, with the overall better recall performance and the less striking differences between the starting room and adjacent room. In comparison, those in the distinct condition had substantially worse performance for unique objects in room two. These findings support the idea of there being a disruption when crossing the boundary as there is such a dip in memory performance across the rooms, suggesting that encoding of room two was hindered with the change in environmental aesthetic. This also supports the idea that the boundary effects are much more prominent when the two spaces are distinct, as the similar condition did not see as considerable a difference as those in the distinct condition. This lack of meaningful difference suggests that those in the similar condition did not register the doorway as an event boundary, or at the least, took less notice of the event boundary and had a better overall cognitive map of the space developed. The findings of this experiment suggest that competitive rooms may rely

more on visual and low-level features for memory which recognition can pick up on. On the other hand, non-competitive rooms rely more on semantic information and the naming of items, which recall can better pick up on.

3.5.4 How are spaces different in the real world?

A large majority of the research on the memory effects of event segmentation have focused on doorways, namely how walking through a doorway can cause forgetting in comparison to an open environment. However, to focus on that one element is to narrow the scope of the effects of event segmentation. In the current study we see, despite both environments having a doorway present, different performances in memory tasks, with performance being influenced by the task as well as the environments. Moving forward, there should be less emphasis on whether a doorway is present and whether that leads to forgetting, and more consideration of the environment those doorways are present in. Doorways serve a function of dividing spaces that have different purposes, layouts, spatial dimensions, and to not take the role of the spaces being transitioned between into consideration when looking at the effect of doorways on memory is not developing a full understanding of the purpose of event segmentation. When we consider real-world locations, some adjacent spaces are radically different, but some are also very similar, comparable to the environments in this experiment. Real-world environments are complex, and we move between a large variety of rooms every day, and the environments we are conducting event segmentation research in should reflect this variance in their design. The findings of this experiment highlight the important role that environment plays in the memory effects of event segmentation, and for the current body of research to largely minimise the role of the rooms themselves to focus on the effects of doorways is limiting our understanding of event segmentation. Reframing our research to be more reflective of real-world environments, and conscious of how complex the spaces we traverse can be, would only be beneficial to our understanding of event segmentation.

There is a discussion to be had on the nature of events and whether simply moving between rooms can be classified as creating new events. As previously discussed, events can take many different forms, such as being spatially bound, temporally dependent, or goal orientated. This experiment required participants to move around a space with one goal in mind, and so, it can be questioned whether events were being created or moved between.

However, this experiment was testing ideas raised by the EHM, where spatial boundaries such as doorways constitute as event boundaries, and so, the layout of the space in this experiment does have an event boundary dividing the space. However, this does raise a good point, of whether egocentric exploration is a series of events. Particularly in the case of this experiment where there is one goal and we are moving between the same two spaces. According to the EHM, this exploration would be considered to crossing an event boundary repeatedly. While some may question the validity of this experiment generating events, the experimental design abides by the conditions of event boundaries as discussed in the EHM, so questions of validity of this experiment highlight the explanatory issues surrounding the nature of events within the EHM.

One consideration for future research would be the visual styling of the spaces. While both conditions were matched for objects, and shared identical layouts, perhaps the use of the science fiction environment was not the fairest comparison. Science fiction often has a visually striking aesthetic and so while the spaces shared the same layout, perhaps the space station may have read as visually cluttered in comparison to the more realistic environment. As a result, encoding in the space station may have been a more difficult task despite the number of objects and the layout being learned being the same across both conditions. Future research should have more comparable art styles between environments to ensure a clearer comparison between memory performance can be made.

The current experiment highlights some of the limitations of event segmentation research, both in methodology and theory. In terms of theory, there should be less ambiguity in the terminology used and more development of the ideas of competition in complex environments. Methodologically, there should be more emphasis on the spaces being navigated between, looking at the effects of the rooms themselves and what components of a space can draw out positive or negative effects on memory.

3.6 Experiment 4- Introduction

3.6.1 Processing transitions between spaces

The previous experiment examined the nature of the spaces being transitioned between and moving beyond considering the effects of a doorway in isolation. An important extension of these ideas of considering more than only the act of walking through a doorway is the transition spaces themselves and thinking about how the spaces we transition through may have an influence on memory performance as well. Research currently gives surprisingly little consideration to how we transition between spaces. Moving beyond looking at whether a doorway is present or not, an important consideration for the effect of event segmentation on memory is the period of transition in itself. The effect of event segmentation would not only be influenced by a transition between two spaces occurring, but also how we transition and the nature of the transition would also have a significant effect on memory performance.

A doorway and corridor provide the same function, connecting one room to another, yet it is unclear whether a corridor would register as its own event due to the size and length of time spent in a corridor, compared to a doorway which provides an instant transition between two event spaces. Ross et al. (2024), found that participants made more frequent event segments, both within and across viewings of a virtual maze, when there were internal walls dictating the route around the maze, as opposed to those who completed an open field maze, where there were no internal walls, and participants were guided around the route. Essentially, when traversing corridors and enclosed spaces, participants are more likely to make more frequent meaningful segments than when in more open spaces without corridors. These findings suggest that traversing corridors, and the time spent in transition spaces, generate stronger segments that are more likely to influence memory performance than the weaker segments created from less time in transition spaces. However, this raises the question of whether a defined transition space such as a corridor generates stronger more defined segments than a doorway, causing larger effects to memory performance. As previously mentioned, while serving the same function, a transition space is that: a space. With doorways being seen as the event boundary in spaces, it remains unclear if transition spaces such as corridors would register as their own events, becoming a mediary event between two meaningful events.

However, we should not only consider the perception of the transition spaces in isolation. With the inclusion of a corridor instead of a doorway, the simple change in the size

of the environment could impact memory performance and how we perceive the space as a whole. Stankiewicz et al (2006) found that as the layout size of an explorable area increased, spatial way-finding efficiency decreased. While the environments in the Stankiewicz experiment remained functionally and visually identical, being a series of hallways, simply making the environment bigger, where the smallest environment was ten corridors long, and the biggest environment was eighty corridors long, was enough to produce a difference in spatial processing. If we apply the findings of this study to event boundaries, increasing the physical size of an event boundary could potentially influence the effect of the event boundary.

Stankiewicz et al (2006), also found that limiting visibility in a space can have an effect on spatial processing. When the visibility of the corridor was limited with a fog, participants were less effective in recreating the route that they explored. It appears as though, despite the participants being able to freely explore the environments, and the environments being identical, with the only difference of visibility, the reduced access to the visual information had a significant influence on spatial mapping and processing. Comparing a doorway to corridor, there is a difference in visibility where doorways mean the stimulus in the adjoining space is closer with a wider field of vision, and so, the amount of information available across the boundary without transitioning between spaces could have an influence. These findings may support the findings of Ross et al. (2024), who found more segments were made when exploring a walled maze. The corridor condition may result in more segments being made, in due to the enclosed nature of the event boundary, resulting in a difference in processing in comparison to the doorway which may not result in as many segments. Similarly, applying the findings of the Stankiewicz experiment, we would expect that those in the doorway condition would perform better than those in the corridor condition due to the availability of visual information.

3.6.2 A neuroscience perspective

When considering how to move forward and adapt the theoretical ideas of the EHM, it is important to consider all aspects of research with regards to spatial processing and navigation. A large portion of this research involves neuro science methods, and as a result, it is important to discuss this research and findings to ensure we are taking a holistic approach

to our explorative research, while ensuring our design paradigms are being supported by established research within the field.

Brain activity differences in how we process doorways and transition spaces as event boundaries could also have an influence on memory performance. There are four types of cells in the brain which are sensitive to where we are and where we are going. First there are place cells, which only fire when we are standing in a specific place in an environment, but do not activate with movement (Pilly & Grossberg, 2012). Second is head direction cells, where a cluster will fire when looking in a specific direction, and when this orientation changes and are looking in a different direction, another cluster of cells will fire more and the first group less so. Third, there are grid cells, which are similar to place cells, however fire in multiple places relative to each other along a given route. Finally, there are border cells, which fire at boundaries and can be used to reorientate ourselves and make sense of a space. In combination, these cells can inform the perception of distance, travel duration, and direction towards next grid marker which are key to understanding spatial memory, as they inform current location, goal location, and how to travel there. As these cell types are very sensitive to location and direction, we would expect to see a difference neural activity when transitioning between spaces when using a door or corridor, despite serving the same function. The place cells would only activate in a single location with a doorway having an instant transition between spaces, where in corridors, we would expect different firing rates throughout the corridor due to the larger spatial area. These cells are thought to collectively instantiate cognitive maps, meaning that any changes in firing rate in the cells due to spatial layout would result in different cognitive maps being formed. If the brain is reacting in different ways despite these spaces being very similar, then we might expect how these spaces are processed and engaged with to be different, as well.

The hippocampus contains these place cells, which would have a significant influence on the memory effects of event segmentation. When there is a change from one spatial context to another, hippocampal place cells show remapping (Jeffery, 2011). By contrast, when multiple spaces/events in an environment are similar, place and grid cells show similar firing patterns between compartments. However, increased place firing rates are observed around doorways, regardless of similarities between spaces (Brunec et al., 2018). When rodents were moving through a series of identical compartments, there was a spike in hippocampal cell firing around doorways, which was followed by place and grid cells

returning to their original firing patterns once the new compartment was entered, This highlights that we would see a difference in how these environments would be processed on a neural level, but the extent to which this would result in differences in memory performance remains unclear. This difference in processing could result in a clear delineation of events, allowing for discrete events to be recalled allowing for greater memory performance in the corridor condition. However, the change in firing when entering a transition space may not allow for information to be carried over, resulting in some information being lost.

3.6.3 Temporal compression of event boundaries

It is clear the brain responds to spaces of varying sizes and layout differently, but the effect if these difference when localised to the event boundary remain largely unexplored. Some research suggests that in transition spaces and passing through event boundaries a temporal compression occurs, where the more meaningful spaces are prioritised and remembered in greater detail, and the transition period is neglected. For example, Jeunehomme et al. (2018) asked participants to wear a camera and walk around a university campus, then were later asked to mentally replay the events, they found that the number of recalled experiences was higher for goal directed actions more so than spatial displacements (moving between meaningful spaces), and also that there were significantly larger temporal gaps during spatial displacements than in goal-directed behaviours. If the process of moving between meaningful events results in lower memory performance as these findings suggest, it could have implications for our understanding of event segmentation and memory. Namely, if a memory effect is not only limited to doorways, but transitional spaces as a whole, there is a large gap in our understanding of event segmentation and memory, and transitional spaces would require more research carried out to determine the extent of these memory effects. These findings are consistent with Jeunehomme and D'Argembeau (2020), who found that the effect of time compression (the ratio of the time needed to mentally re-experience an event to the actual event duration) at spatial displacements was stable after one week and the amount of time compressed increased after one month. These studies raise a point about our understanding of an event boundary in space: in these experiments an event boundary was not defined as a stable location dividing spaces but was instead defined as the period of transition between two meaningful events.

When we consider how we recall information and how memory is represented, the continuous flow of experience is not represented as such. Events are instead recalled as a succession of moments that includes temporal discontinuities, where portions of the past are excluded when recalling events (D'Argembeau et al., 2022). Looking at Jeunehomme and D'Argembeau (2020) and D'Argembeau et al., (2022) they suggest that priority is given to meaningful events, events which are focused around a specific goal, or have a high level of detail in which may be of use or meaning to us. Due to this high priority, meaningful events can be removed from their temporal context and recalled in isolation, whereas the process of transition is intrinsically linked with these meaningful events, and yet is not recalled with as much accuracy or detail due to their lower level of priority. These experiences of transition spaces, despite being important to achieving goal related behaviours are not afforded the same importance. While this effect is unsurprising, what remains surprising is the extent to which we see temporal compression occurring when not in meaningful events. While doorways divide spaces into meaningful events and thus are a good visual representation for this divide, it is not the only way we transition between meaningful spaces. There are numerous forms liminal spaces can take which could also be considered an event boundary as they act as a transitional space, for example, elevators, corridors, stairways etc. However, in the research surrounding the EHM and event segmentation, there is a large emphasis on doorways as event boundaries, and comparatively less on other forms of transition spaces. If we reframe our idea of an event boundary not to be a hard boundary with a single physical representation in space, but more so as the means of transitioning between one meaningful event to the other, we may discover some useful insights into event segmentation which have not currently been considered. In the previous experiment, we highlighted the importance of rethinking our approach to the meaningful events on either side of a doorway, and with the current experiment, we may develop a different approach to understanding transitioning between meaningful events. With these two experiments together, our understanding of event segmentation may be reshaped, with new insights into influential factors in the spaces that make up meaningful events, and the memory effects that may emerge in the spaces between those meaningful events.

3.6.4 Aims and objectives

The primary aim of Experiment 4 was to determine whether memory performance for a space is affected by the presentation of the event boundary. In particular, we were interested in whether there is a significant difference in memory performance when the event boundary is presented as a doorway or a corridor. The original principles of the EHM do not give much consideration to the nature of the event boundary, so we cannot make significant predictions based on the original model. However, based on previous research into spatial navigation, as well as neuro science research into cell firing when navigating spaces, we should expect a significant difference in memory performance between the two conditions, due to the size and dimensions of the environment changing, the brain will process the two scenes differently. The increase in scale of the space in the corridor condition may make it more difficult to remember, due to more information needing to be processed or, alternatively, the corridor condition may even register as a third smaller event.

Based on previous work on the topic, we hypothesised that there would be a significant difference in memory performance for a common set of objects between those in the doorway and those in the corridor conditions.

3.7 Methods

3.7.1 Participants

Forty-eight participants were collected from the University of East Anglia, with a mean age of 20.40 years ($SD = 4.15$), made up of 33 female, 14 male, and 1 non-binary participants. These participants were recruited using the University of East Anglia's School of Psychology Research Participation Scheme. Participants were offered two course credits for completion of the study. Participants were randomly allocated to each condition, and so, participants were not matched for variables in their allocation.

Similar to experiment 3, an n of 81 would be needed for an appropriately powered study based on the effect sizes from Lawrence & Peterson (2016). As a consistent n was used throughout the first four experiments in this project, a post hoc power analysis was used to

determine the achieved power of the study. With an n of 48 and an effect size of .654, the achieved power of this study was .72, meaning the results of this study are slightly underpowered in comparison to the standard of .8.

3.7.2 Design

As outlined in the general methods in the previous chapter (Chapter 2.2.2), this experiment used a between participants design. The experiment consisted of two parts, where part one was the exploration phase in a VR environment, while part two was the test phase where participants completed two memory tests: a free recall task and a forced choice recognition test.

As a result, the dependent variables were the participant scores on the free recall task and forced choice object recognition test. The independent variable was the presentation of an event boundary in an environment, whether the event boundary was a doorway with instant access between spaces, or a corridor with a longer transition process. We were interested in whether there would be a difference in memory performance when participants had immediate access to both spaces through a doorway as opposed to when there was a buffer period between the spaces in the form of a corridor.

In both conditions, the exploration phase lasted for five minutes, where participants could freely explore the virtual environment. For those in the corridor condition, they were held in the transition space for two seconds to highlight the transitional space. The test phase of the experiment was untimed, where participants could spend as much time as they needed on both the free recall and the forced choice recognition tasks.

3.7.3 Materials and Stimuli

In both conditions, the virtual environment consisted of two small rooms including a bedroom and a kitchen/living space, both filled with objects that were to be remembered (Figure 3.5). The rooms were either separated by a doorway or a short corridor (Figure 3.6). The objects and placements in the rooms were consistent across both conditions with the only difference being the presentation of the event boundaries. The doors for the corridor were

controlled by the researcher, in order to hold the participants in the transition space for two seconds.

Figure 3.5

Two Apartment Rooms being explored in both conditions



Figure 3.6

Difference Between Conditions in the Presentation of the Event Boundary Dividing the two Rooms of the Apartment

A)



B)



Note. A; Doorway Condition, B; Corridor Condition

Software for the study remained the same, with the exception that the code required for the movements of the doors and collision of objects, which were required to hold the participants in the corridor condition, were written in Microsoft Visual Studio using C#.

3.7.4 Procedure

We followed the same general procedure outlined in Chapter 2.2 (Page 39). However, one difference in the procedure for this experiment was that while participants could freely explore the space, those in the corridor condition were held in the corridor for two seconds when they wanted to cross between the two spaces. This holding in the space was to ensure the participants would experience a longer transitional period than those in the doorway condition, and this buffer period would be recognised and acknowledged. For those in the doorway condition participants could freely move between the two spaces and there was no delay in access between spaces. All participants started the experiment in the kitchen/ living space.

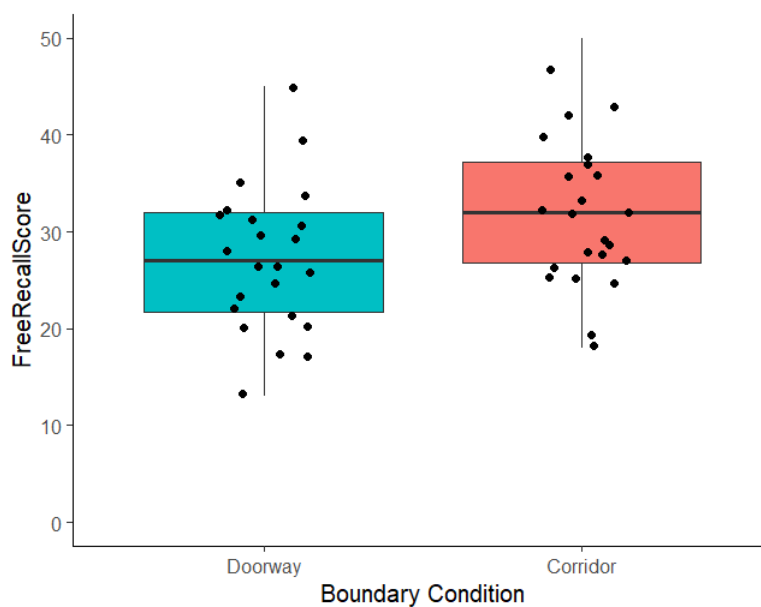
3.8 Results

3.8.1 Performance on the Free Recall Memory Task

Using an independent t-test, there was a significant effect of boundary presentation on free recall performance, with those in the doorway condition performing significantly worse ($M = 27.25$, $SD = 7.46$) than those in the corridor condition ($M = 32.38$, $SD = 8.20$); $t(46) = -2.27$, $p = .028$, $d = -0.654$, $CI = -9.68 - -0.57$.

Figure 3.7

Average Free Recall Scores by Boundary Condition, Comparing a Doorway and Corridor Boundary

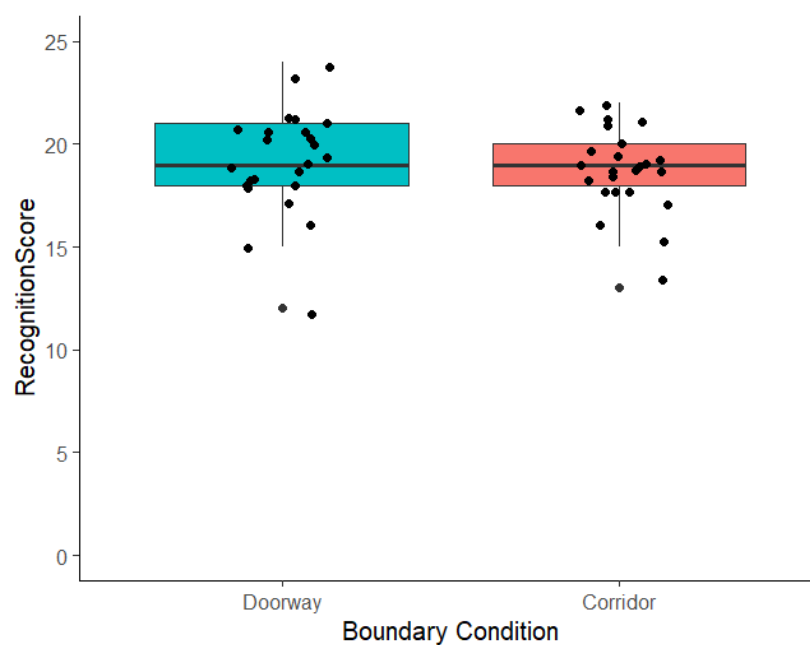


3.8.2 Performance on the Forced Choice Recognition Memory Task

We investigated whether how participants traversed between two rooms - doorway or corridor - would have an effect forced choice recognition memory. An independent t-test showed that there was no significant difference in recognition scores between the boundary conditions, with those in the doorway condition ($M = 19.13$, $SD = 2.56$) performed similarly to those in the corridor condition ($M = 18.75$, $SD = 1.51$); $t(46) = 0.62$, $p = 0.54$, $d = -0.178$, $CI = -0.85 - 1.59$.

Figure 3.8

Average Forced Choice Recognition Score by Boundary Condition, Comparing a Doorway and Corridor Boundary



Note. Maximum score was 25

3.8.3 Performance on Memory for Unique Objects Proportionally per Room

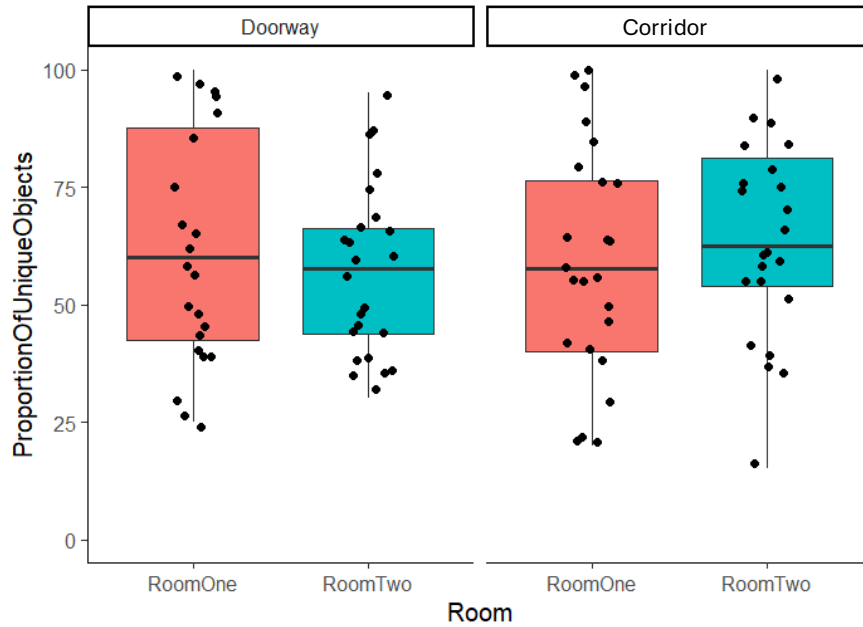
The effect of boundary condition (doorway or corridor) on memory for unique objects across each half of the environment (Starting and Adjoining Rooms) was investigated using a 2x2 mixed design ANOVA, with the boundary condition acting as the between condition, and

the environment half acting as the within condition. Results indicated that there was no significant main effect of boundary condition: there were no significant differences between the doorway condition ($M = 60.52\%$, $SD = 22.25\%$), and the corridor condition ($M = 62.08\%$, $SD = 23.36\%$); $F(1,46) = 0.062$, $p = .804$, $\eta_p^2 = 0.001$, $BF_{01} = 0.492$. There was also no significant main effect of test room, with no differences in the proportion of unique objects recalled in Starting Room ($M = 61.58\%$, $SD = 25.08\%$), or Adjoining Room ($M = 61.04\%$, $SD = 20.32\%$); $F(1,46) = 0.065$, $p = 0.80$, $\eta_p^2 = .001$, $BF_{10} = 0.220$. However, a significant interaction effect was found between the effect of boundary condition and test room; $F(1,46) = (8.39)$, $p = .006$, $\eta_p^2 = .154$.

As an interaction was found between boundary condition and which half of the environment unique objects were being recalled from, two further t-tests were carried out to establish the interaction effect. The first t-test found that there was no significant difference in the proportions of objects recalled from either half of the environment when participants were in the doorway boundary condition, where the Starting Room ($M = 63.96\%$, $SD = 26.00\%$), and Adjoining Room ($M = 57.29\%$, $SD = 18.18\%$) showed similar levels of proportions of unique objects recalled; $t(23) = 2.03$, $p = 0.054$, $d = 0.42$, $CI = -0.12 - 13.45$. However, there was a difference in the proportion of unique objects recalled between rooms when the event boundary was presented as a corridor, where a significantly lower proportion of unique objects were recalled from the Starting Room ($M = 59.38\%$, $SD = 24.82\%$), than from the Adjoining Room ($M = 64.797\%$, $SD = 21.99\%$); $t(23) = -2.20$, $p = 0.038$, $d = 0.45$, $CI = -10.51 - -0.32$.

Figure 3.9

Relative Proportion of Unique Objects Recalled in each Room by Boundary Condition



3.9 Discussion

3.9.1 Overview of Results

Unlike the previous experiment, we did not observe a significant difference in memory performance when testing for recognition ability. In comparison, we found both significant differences in performance between the boundary conditions in the free recall task, as well as a significant interaction in the number of unique objects recalled in the environment rooms dependent on the event boundary presentation. These results suggest that the type of memory affected by event boundaries is dependent on the task and the presentation of the event boundary. Where in the previous experiment, we saw significant differences in all tests, here we only see measures testing free recall show significant differences. With these observed effects, we can argue that the role of transitional spaces in memory is somewhat selective. No evidence supported the influence of transitional spaces on recognition, suggesting that our ability to distinguish fine grained differences in images is not altered by the differences in transitional spaces. This could be due to the focus on individual objects or subsections of a space being less dependent on the overall environment, and so how a transition is experienced may be less important. However, differences in the transition space are important with regards to free recall, as changing the boundary experience resulted in significant differences in our ability to freely recall objects from the environments.

Namely, we see those in the corridor condition show better recall performance than those in the doorway conditions. Perhaps the emphasised segmentation of the two main rooms aid in the compartmentalisation of space and reinforce participants ability to segment the space into two distinct events, aiding in recall performance. However, as this effect does not cross over to the recognition measure, recognition ability is perhaps more dependent on the spaces being segmented, as we saw in the previous experiment, rather than the nature of the event boundary.

3.9.2 Recognition

In this experiment, we were interested in how a boundary's presentation can result in changes in memory performance, namely, is there a difference in when an event boundary is presented as a doorway as opposed to a corridor. We found that there was no significant difference in recognition scores between the doorway and corridor condition. These findings suggest that the nature of the boundary and how we transition between spaces may not significantly impact our ability to recognise stimulus from that environment. In discussing these results, we consider the functionality of corridors and doorways. They are both methods of transition between two meaningful spaces that do not alter goal orientated behaviour, nor do they impact the content of the rooms on either side of the transition. While there has been a large focus on the role of doorways in event segmentation, the effects of event segmentation on memory can be explained as moving between events, of one event ending and another beginning, and that effect is not unique to doorways. Other representations of event boundaries would, in theory, also generate the same reported effects of forgetting which previous research has found. With this in mind, if other representations of event boundaries are producing similar responses to doorways, then it supports the idea that we need to reframe our ideas around event segmentation and how research is being conducted on the topic, by not focussing so much on doorways causing forgetting. It would be useful to frame the effects in the context of moving between events or the transition point, and less so highlighting doorways, in particular, when the memory effects they generate may not be unique.

These results support some of the ideas raised in the theory of temporal compression in transition spaces. In this experiment, the rooms on either side of the event boundaries were identical, with the only difference being the presentation of the event boundary, whether it was a doorway or corridor, and there was no influence of this variable on recognition scores.

Perhaps a similar effect as was observed by Jeunehomme et al. (2018), was occurring, in which the period of transition was being neglected to focus on the goal orientated behaviour. If temporal compression of the event boundaries was occurring, it would mean that participants in both conditions were essentially exploring the same environment with a transition point in between, and thus, we would not expect there to be any significant differences in memory performance. However, as we were not specifically testing for temporal compression, as we did not participants to estimate their time in the transition space, we can only draw similarities between the two sets of work. Drawing this comparison between the current work and Jeunehomme et al (2018), highlights the lack of research investigating transition spaces. These findings are somewhat novel due to the experiment focusing on differences in transition, and there is little research to compare the findings of transition spaces to. While temporal compression may be an explanation for the current findings, further research is needed into transitional spaces to investigate what memory effects may be occurring.

These findings suggest that the current approach to event segmentation research could evolve in the future, as there are some concepts, such as temporal compression, which remain largely unexplored. For example, if we compress and neglect event boundaries, then what moments or locations which are considered event boundaries could be much more than currently being considered. Similarly, with compression, the definition of an event becomes unclear, such as significant times spent transitioning between meaningful events could become events in themselves. And these effects may not necessarily be limited to space, for example, these ideas may also be applicable to the period between the completion of one task and the beginning of another. When Jeunehomme and D'Argembeau (2020), explored temporal compression, they asked participants to walk around a university campus, not through doorways or corridors, and while campuses are segmented with proximity to buildings or landmarks, there would have been less explicit physical boundaries than we see with research focusing on doorways. If we reframe our research less so around doorways and forgetting and explore ideas around the perception of transitioning between events, there could be a number of effects we may not yet be considering which could be occurring, such as this temporal compression. Some examples of research ideas are testing participants experience of time and perception in transitional spaces, having some stimulus to remember in the transitional spaces and compare to memory for stimuli in the main rooms, or altering

how long participants are in the transition space to determine if any observed memory effects are compounded by time in transition spaces.

3.9.3 Free Recall

We aimed to examine whether the presentation of an event boundary would have an effect on memory performance, whether the difference between a doorway and corridor would exacerbate any forgetting effects. We found that there was a significant effect of boundary condition on free recall performance, with those in the corridor condition scoring significantly higher than those in the doorway condition. When looking at free recall, we can see the differences in transition spaces matter more, indicating that how we move between meaningful spaces does still have an effect on memory performance. These findings are in contrast to the recognition results, where there was not a significant difference in performance between the two conditions. Such a profile in the recall results is consistent with neural differences in the processing of space, as the differences in the environment layout and size due to the differences between a doorway and a corridor would result in the brain processing the space differently. When we consider the hippocampal firing rates discussed before, where there are different firing rates when changing from one spatial context to another, perhaps the brain needs a significant transition space, such as a corridor, to act as contrast to the meaningful events, being the two main rooms. Time spent in transition may have been needed to consolidate the information from both rooms into discrete events that were probed with the demands of this particular memory task. Results from the previously discussed neuroscience studies show that the brain is sensitive to boundaries, orientation, and place, with different cells being dedicated to each function. These cells play a pivotal role in the development of cognitive maps, and so, with the inclusion of a transition space, enclosed by boundaries and with a single direction to travel through, we would expect that some differences would emerge in how these scenes and their constituent elements were processed and remembered. The inclusion of an additional space may change hippocampal cell firing rates when processes the space and builds a map, changing how we engage with, navigate around, and remember a space.

In terms of functionality, doorways and corridors share the same functionality in allowing for the transition between spaces, however, a corridor is, in itself, its own space, whereas a doorway is not. Perhaps the transition through a corridor is long enough to act as

its own event, not a meaningful event that would compete with the two rooms, but a simple event which highlights the event boundary even more than a doorway.

As in Experiment 3, we can see some benefits to memory performance, such as recognition in Experiment 3 and free recall in Experiment 4 when the event boundaries are more evident. It may be a similar effect here, where the corridor presents a more pronounced event boundary experience as opposed to a doorway, which allows for immediate access between two meaningful events. This idea supports the findings of Ross et al. (2024) who found more frequent and stronger segments were made in transitional corridors in a maze, as opposed to when the maze had no internal walls. It may be the case that a corridor as an event boundary produces more pronounced segments, making the division between the rooms more explicit due to more time spent between events, thus aiding in memory performance, in a way that doorways do not.

3.9.4 Reframing the Event Boundary

The current experiment explored whether other presentations of the event boundary would change memory performance for a scene. While results were mixed, it is clear that our understanding of event boundaries has been limited with a focus on doorways in particular. The work of Jeunehomme et al. (2018), explored the idea of temporal compression when transitioning between events, an idea which could have significant implications for our understanding of event segmentation, and yet, remains an understudied idea due to the emphasis on “doorways cause forgetting”. By focusing on doorways, there cannot be much examination of any transition effects due to the immediate traversal of the boundary. In the current study, we looked at whether doorways and corridors would result in differences in memory performance in free recall and recognition tasks. As they share the same function, the spaces on either side of the transition were identical, the only difference being the presentation of the boundary, the length of time spent transitioning between spaces. There is some influence on changing the transition space between events, but it is not as simple as more or less time in transition produces positive or negative results. With no significant differences in memory performance on the recognition test, nor main effects of condition or room for free recall of unique objects, it appears as though the importance of the event boundary is somewhat limited. However, there were significant differences in free recall, and a significant interaction between condition and room for recall of unique objects. The

significant results of this experiment suggest that the effect of the presentation of the event boundary may have more of a specific and specialised memory effect, as opposed to the more general overall effects observed in the previous experiment.

A potential explanation for this superior free recall memory performance in the corridor condition is that with the changes in hippocampal cell firing rates being more strongly emphasised by a corridor over a doorway, encoding for space may be enhanced by the corridor, resulting in superior performance. Similarly, the corridor may emphasise the segmentation between the spaces, due to the corridor being treated differently on a neural level. However, with recognition, the information is being primed with images of the space, and so any superiority caused by the corridor may be reduced, as participants have some stimuli from the environment in the image. It appears as though the difference in event boundary presentation have some significant but focused effects on memory.

All event boundaries are not labelled or identified as a doorway, and yet that is where a majority of the research has gravitated towards. If we reframe our ideas around event segmentation to be more conceptional in nature and less of a literal interpretation, we may discover effects that were not being considered before. When looking at the event segmentation in physical space, an event boundary is not limited to a physical boundary in the space bisecting meaningful events localised to specific areas. With Jeunehomme et al. (2018), participants were walking around outside, an often underutilised method of exploring event segmentation. Yet participants were able to identify meaningful events, it was clear to the researchers when the transitional spaces occurred, and they were able to conceive of the idea of temporal compression. Event segmentation is not a simple process with a single effect on memory, where doorways cause forgetting, it is how we organise and make sense of a stream of consciousness, and so it will be multifaceted and complex with several influences. If we reframe our ideas around event segmentation to be more conceptual and less beholden to features of the physical environment, we may be able to identify and study influences on memory which are not yet being considered.

3.9.5 Future Directions

Reviewing the experiments in the current chapter, there are some recommendations which can be made based on the limitations of these experiments. For the first experiment,

there could be a range of environments of different levels of similarity to assess how much similarity of difference results in changes in memory performance. Rather than having two environments of different ends of the spectrum, having a range of different levels of similarity would allow researchers to identify a threshold to cross for memory effects of event segmentation.

Meanwhile, for the second experiment, a recommendation for further research would be to expand the different types of event boundary further. The current experiment utilises a doorway and corridor, however, future research could expand the length of the corridor further to examine the effects of being held in the event boundaries for different lengths of time. Similarly, if future research included other forms of event boundary, such as an elevator, an outdoor pathway, or a stairwell, we would be able to explore the effects of different methods of traversal further than Experiment 4 currently does.

More general limitations which could be addressed with future research is the methods of testing memory. While the research paradigm used examines free recall and recognition, having other tasks such as a navigation task, or searching task would develop a more complete idea of the effects of event segmentation on memory performance. Asking participants to actively search and move around an environment would inform the behaviours which people utilise in the space and how they engage with the space, rather than only assessing memory after exploration is complete and they are no longer in the environment. Another potential suggestion for future research would be to combine the ideas explored in Experiment 3 and 4. Research could explore the differences between two spaces of varying levels of similarity across different types of event boundaries. Combining these two ideas would allow us to explore whether there are any interaction effects between these features of the environment, and whether the event space or event boundary is more influential in affecting memory performance.

3.10 Conclusion

From the two experiments in this chapter, the effects of event segmentation on memory cannot be attributed to doorways alone. Both experiments had doorways in all conditions and yet, there were still a mix of significant and non-significant effects on different types of memory performance. With these results occurring when manipulating both

the environments and the environmental boundaries, the process of event segmentation is much more complex than current research is giving consideration to. Experiment 3 explored the effect of competition and what makes stimuli competitive to begin with, by looking at differences in free recall and recognition performance between aesthetically similar and distinct spaces. There is a need to revisit the EHM and explore these concepts in further detail, to refine them to be clearer and more useful, as currently, there is an ambiguity in the lack of refinement of these ideas which leave unanswered questions to what influences in memory we should expect in certain conditions.

Conversely, in Experiment 4, we explored the concept of event boundaries, and how doorways alone are not the only form of event boundary when moving between meaningful events. This experiment highlighted the restrictions of focusing on doorways, as significant effects on different memory tasks were observed depending on whether participants experienced the boundary as a doorway or corridor. Exploring how different forms of event boundaries can affect memory performance was illuminating, as it emphasised the need for exploration of more novel ideas in this topic, with the finding of both significant and non-significant differences in memory performance. These findings show that different forms of event boundaries can have an influence, as seen with the results of the free recall task, but also, despite significant differences in the event boundaries, performance remains the same, as seen in the results for the recognition test.

While both of experiments in this chapter provide rich routes to pursue for follow-up research, a different approach will be taken up following this work. A theme throughout this chapter was the reformation of ideas, such as what factors should we consider in a space, how does changing an event boundary effect memory. Moving forward, we should continue to expand our ideas on event segmentation and look at what other cognitive processes may be affected. Up to this point there has been a focus on recall of the spaces after exploration, however, a big part of moving between spaces is how we navigate around space and the generation of cognitive maps. And so, the next stage will be to explore the effects of event segmentation on the generation of spatial maps, moving beyond the recall of information from the spaces.

**Chapter 4 –
Exploring the effects of event segmentation on Route Learning**

Chapter 4 – Exploring the effects of event segmentation on Route Learning

4.1 Introduction

Following the results of the previous two chapters, we took a different approach to looking at event segmentation, moving beyond a singular memory effect of event segmentation, and examining if memory effects present themselves in other ways. For example, how is route learning influenced by event segmentation. The results of Chapter 2 showed that a doorway alone is not enough to produce a difference in memory performance for a space, whereas Chapter 3 highlighted how memory performance could be influenced by the aesthetic presentation of the spaces divided by a boundary, as well as the presentation of the event boundary itself. Together, these results highlight the complexity of event segmentation, and how it is not as straightforward a process as having a memory effect when crossing between events. As a result of the developing complexities of event segmentation, we began to consider the purpose of moving between spaces and how we move through environments. This led to looking at event segmentation under a different context, to move beyond recall and memory research and to look at other topics such as route learning and route formation. Exploring route learning and formation would allow for event segmentation to be analysed under new contexts, while still focusing on moving between events, and the influence of doorways on memory for a given environment.

4.1.1 Prediction Error

The brain is always making predictions about the world around us, anticipating what is about to happen based on past experiences and contextual information. When events do not follow these predictions, a prediction error occurs, where the brain updates its assumptions and representations of the situation based on the new, unexpected information (Nolden et al., 2024). Prediction error can have an effect on memory performance, such as enhanced memory encoding. An example of this could be a disruption to your morning routine with an unforeseen event, as the unpredicted event results in experiencing a prediction error, which would stand out and be easier to recall than other memories from an uninterrupted morning routine (Frank & Kafkas, 2021). This in turn can have an effect on future predictions, where the unexpected information which caused the prediction error may interfere with the retrieval of previous information (Frank & Kafkas, 2021), for example, it may be more difficult to

remember events before and after the disruption to the morning routine, thus the disruption will have a significant influence on future preparations.

Researchers have identified that prediction errors influence what can constitute as an event boundary. Event segmentation is a forward orientated process, anticipating and generating when a segment will occur, which is influenced by when past experiences began and ended. From the beginning of event segmentation research, event segmentation and prediction error have been linked due to the predictable nature in which events occur in our daily lives (Kurby & Zacks, 2008). Research supports the relationship between prediction error and event segmentation, for example, Zacks et al. (2011) asked participants to watch a movie and make predictions of what would happen next. Predictions were more accurate within events than across events, suggesting that event boundaries are more likely to constitute when predictions are violated, and in turn, prediction error may be a good indication of an event boundary being created.

However, this does not imply that event segmentation and prediction error are the same process nor dependent on each other where one cannot occur without the other. Event segmentation still occurs at predictable transition points unlikely to produce prediction error, under conditions of consistent sensory input aligning with predictions. For example, in an experiment by Pettijohn and Radvansky (2016), similar responses to memory probes were reported after a contextual shift in a reading task, where memory performance was similar whether the shift was foreshadowed or not. Foreshadowing was carried out by providing an appendix alongside the passages to be read, where they would indicate a shift in events would be occurring, but not explicitly state what the shift was, for example “the character would need to go to bed soon”. The similar findings suggest participants responded to shifts in context regardless of whether they would have high predictability through foreshadowing, or high prediction error without foreshadowing. Event segmentation is influenced more by the individuals internal state, where changes in goals, motivations and inferences can generate segmentation to occur. An example of this would be with a morning routine again, where you have completed one action in the routine, such as having breakfast, the next action, such as getting dressed, would act as a boundary due to the progress in motivations and goals. The process of event segmentation goes beyond anticipated alterations to our environment. We do not only encounter event boundaries with physical changes in the environment, such as moving between different rooms, but actions and behaviours can also result in event

boundaries. It is more likely that prediction error plays a role in processing contextual changes, alongside internal factors and environmental influences.

While prediction error and event segmentation do share some similarities and event segmentations uses predictions to predict when segments may occur, there are significant differences in their effects on memory. Research has shown that when expectations are violated, memory performance is enhanced. For example, Bein et al. (2021), found that when objects were shown in pairs repeatedly to generate expectations, then violated these expectations by showing an unpaired object, memory for the objects that violated expectations was superior to memory for the paired objects. Furthermore, it is not only that any prediction error enhances memory, but the stronger the prediction error the stronger the memory enhancement. Greve et al. (2017) presented participants with scene and item pairings to learn, then new scene-item pairings were presented with varying levels of mismatch; memory was best when prediction error was at its strongest. The research surrounding prediction error and memory would indicate that memory for objects or information across events would be superior to memory within events, but research into event segmentation shows the opposite. When there is a shift in context, such as walking through a doorway, memory performance for objects is significantly lower than objects presented in the same scene as being recalled in (Radvansky et al., 2015). The forgetting nature of event segmentation has even been shown to be exacerbated with prediction, where anticipating crossing an environmental boundary can trigger active forgetting (Wang et al., 2023).

Looking at the processes of event segmentation and prediction error together, the processes do appear complimentary, yet at odds. In Wang et al. (2023), there was little prediction error in that experiment, as it focused on anticipation of contextual shifts. In this experiment, participants learnt a list of words, then watched an immersive video simulating walking through a space. Even when tested *just before* walking through a doorway, there was still an impairment to memory performance in comparison to no doorway participants. Here we see memory effects when participants could accurately predict they would be moving through an environmental boundary. [The effects of prediction error has been explored through the work of Quent et al. \(2022\), who explored the relationship between object-location memory and expectedness. They found when testing for object memory with varying levels of congruency with a kitchen schema, a U-shaped pattern emerged, where](#) memory was better in location recall and forced choice recognition

when objects were either highly expected or unexpected, relative to neutral locations. These findings highlight the role of schema in shaping spatial memory encoding, where they both facilitate the encoding of expected information or highlighting unexpected information. This U-shaped pattern was supported by a neuroimaging review by van Kesteren et al. (2012), who identified key brain regions, such as the medial temporal lobe (MTL) and medial prefrontal cortex (mPFC) as important in encoding, consolidation and retrieval of information as a function of its congruency with existing information. Despite this strong basis of evidence, some aspects of superior recall remain unclear, such as meaningful differences between high congruent and high incongruent recall. When there are unexpected shifts in stimuli that result in a prediction error, we would expect to see some enhancement to memory for the new stimulus, as was highlighted with the previous example of the morning routine. However, if that stimulus is now in a new context or across a new event boundary, it becomes unclear if we would still expect memory enhancement or would the forgetting effects of event segmentation take over. For example, if in the morning routine, we were taken to a space we do not normally visit in our morning routine, would memory for these events be enhanced, or would the event boundaries be too distinct that we cannot link the memories together, resulting in forgetting between events. These processes are closely linked, with event boundaries often being generated through prediction, and prediction error can result in a shift in context, such as crossing from one event to another. However, it remains unclear how these processes interact in scenarios of high prediction error and multiple segmented events.

4.1.2 A Neuroscience Perspective

When carrying out research around the ideas of event segmentation, route learning and navigation, it is important to consider the influence of local and global processing. A large body of work surrounding local and global processing uses neuroscience research to investigate ideas. While this project focuses more so on behavioural studies to explore these ideas, it would be an oversight to research this area without acknowledging the large neuroscience body of research to provide more context for the ideas we are examining. This section aims to address this research and explain what we can learn from previous research, thus not overlooking a large piece of the current topic understanding, which can still be used to provide context for our research ideas, even if not using neuroscience research methods ourselves.

Local processing is where there is a focus on the fine grain details, such as individual objects within an environment, and attend to the individual components of a scene, rather than the overall scene (Strickrodt et al., 2019). Global processing, however, is looking at the context and the overall space, looking at the boundaries and the overall meaning of the scene rather than the individual objects which make up an environment to develop an overall view of the scene (De Cesarei & Loftus, 2011). Neither of these processes happen in isolation, but rather are intrinsically linked: local information provides expectations of what to find in a type of environment, while global information provides the contextual knowledge for objects and components of a scene. Global and local visual processing are associated with the scene processing network, made up of the Parahippocampal Place Area (PPA; Aminoff & Tarr, 2015), the Retrosplenial Cortex (RSC; Vann et al., 2009), and the Occipital Place Area (OPA; Dilks et al., 2013). This neural network processes visual information while navigating. However, this network is sensitive to environmental boundaries, and the relationship between the objects that make up a visual scene and the environmental boundaries surrounding them (Bilalić et al., 2019). With this sensitivity to boundaries in mind, it appears as though event segmentation could have an influence on the activity within this neural network.

Research into the PPA has shown its importance in navigating around spaces, where patients with lesions involving the area have trouble navigating both familiar and unfamiliar environments (Epstein et al., 2001). On top of this, the PPA has been shown to have a significant role in landmark identification during navigation as well, learning the different features of a landmark (Marchette et al., 2015). However, there is little influence of more local information, fine grain details and smaller objects on PPA activation, as the PPA has been shown to respond similarly to empty rooms and rooms with objects in them if the boundaries of the space are the same (Epstein & Kanwisher, 1998). This research makes it clear that the PPA plays a pivotal role in navigating spaces, using global information to identify a space, and when there is an issue with the PPA, navigational ability is impaired.

However, the PPA is not solely associated with navigation, and shows activation outside of navigational contexts. When viewing a set of images, the PPA responded stronger to images of scenes, in comparison to faces or objects. This increased responsiveness was present whether participants were asked to discern a series of images from each other, or whether they were passively viewing the images (Epstein, 2005). These findings highlight how the PPA responds automatically to scenes, whether participants are actively engaging in

navigation or not. Other research has found that the PPA is prone to recognition errors in confusing scenes which have the same environmental boundaries (Park et al., 2011). The PPA does not only attune to boundaries in navigation tasks but appears to be heavily responsible for the processing of environmental boundaries in a lot of different processes. For example, stimulating the PPA can result in visual hallucinations of shifting to different environmental contexts (Mégevand et al., 2014). Mégevand et al. (2014), found that when the PPA received electrical stimulation, the patient described seeing both indoor and outdoor scenes, including views of the neighbourhood he lives in. With this heightened sensitivity to environmental boundaries, perhaps there is a link between PPA activation and event segmentation. With crossing through environmental boundaries being a large focus of the memory effects of event segmentation, the PPA could potentially have a role in that phenomenon.

However, the PPA does not work in isolation and is strongly associated with the RSC, which also has a vital role in the processing of global information, representing global spatial arrangements (Kamps et al., 2016). However, the specific role of the RSC is not as well defined as the PPA, due to being heavily interconnected in an array of brain networks (Mitchell et al., 2018). Some ideas of its function include learning landmarks, integration between spatial reference frames, and the consolidation and retrieval of spatial knowledge schemas. Unlike the PPA, the RSC is not limited to only processing global information such as environmental boundaries, but also responds to objects within the environment, namely object relations to the global information, as well as the spatial layout of an environment (Bilalić et al., 2019). The RSC appears to be more focused on the integration of knowledge in a space, to not only be sensitive to the global information, but to apply that information to the features within a space too. Alexander et al. (2023), provide some perspective on the role of the RSC in scene perception, where they argue it is the role of the RSC to translate and integrate information between detailed local cues and coarse global cues.

Similar to the PPA, the RSC has a role in navigation. Patients with damage to the RSC were still able to identify scenes and landmarks; however, they were unable to use these landmarks to orientate themselves or navigate a larger environment (Aguirre and D'Esposito, 1999). These findings are in contrast to those with damage to the PPA, where patients with damage to the PPA struggled to identify scenes and landmarks (Mendez & Chérier, 2003). With this contrast of results, it appears as though these two regions play distinct but

complimentary roles in the processing of visual scenes, where the PPA processes the physical properties of an object context, where the RSC processes each scene within a framework, or as part of a broader memory. With these responses to global information in mind, there is a likelihood that the RSC is also involved in the process of event segmentation, perhaps even more so than the PPA. Event segmentation and crossing through event boundaries is influenced by shifting contexts and the object relations across contexts, and these are factors which the RSC would be highly sensitive to.

The OPA is also involved in this neural network, however, its function is less clear in comparison to the PPA and RSC. It is thought that the OPA represents local elements of a scene within two scene descriptors: relation to spatial boundaries, and scene content (Kamps et al., 2016). Kamps et al. (2016), found that the OPA responded similarly to images of intact rooms and these same rooms fractured and rearranged, suggesting that OPA is sensitive to the presence of these surfaces independent of their coherent spatial arrangement. They also found that the OPA responded more strongly to furniture than the PPA and RSC. It was also sensitive to the amount of furniture, suggesting that OPA represents local elements of scene content individually. However, while processing local elements of a scene, the OPA is not sensitive to aesthetic changes to local information. As shown by Henriksson et al (2019), who found that participants encoded spatial layouts at the same rate, with no influence of changes to surface textures.

While the OPA plays a role in processing local elements of a scene, other research suggests that it is not limited in function to local processing. When the OPA is disrupted with transcranial magnetic stimulation (TMS), participants ability to use boundaries, but not landmarks, in a navigation task becomes impaired (Julian et al., 2016), suggesting the OPA is a perceptual source of the boundary information that controls navigational behaviour. However, the functionality of the OPA appears to be dependent on the task and perspective because the OPA is more so involved in egocentric navigation as opposed to allocentric strategies (Ramanoël et al., 2019). Similarly, the OPA was found to respond significantly more to video clips of walking through a scene from a first-person perspective, than images from the same videos, relative to the PPA and RSC (Kamps et al., 2016). Research around the OPA suggests that it responds to both local elements and boundary information in spatial navigation tasks. The effect of event segmentation on the OPA remains unclear, however, as

it is less orientated around global processing and responds to scenes differently from the two other regions in this neural network.

This neural network shows a lot of reliance on boundaries in scene processing on a neural level, for both global and local processing. However, the influence of boundaries in these brain regions would imply that these areas are also sensitive to event segmentation, such as crossing through doorways and moving between events. With these areas being responsible for the processing of local and global information in scene processing, the effects of event segmentation on the processing of local and global information could prove insightful into our understanding of event segmentation.

4.1.3 Aims and Objectives of Experiment 5

With this experiment, we sought to establish the role of event segmentation in route formation and learning. Research surrounding the OPA (Kamps et al., 2016), the PPA (Park et al., 2011), and the RSC (Bilalić et al., 2019), have shown that this neural network is very sensitive to boundaries and uses them in navigational tasks and orientating participants in an environment. The current experiment wished to take the concept of boundaries and focus on how event segmentation applies to route learning. With how sensitive this neural network is to environmental boundaries, we would expect that focusing on boundaries and doorways throughout a route would have a significant impact on how that route was learned and engaged with.

On the other hand, we also wished to explore the relationship between prediction error, event segmentation, and route learning. From Kurby and Zacks (2008), prediction error and event segmentation have been linked; however, their relationship remains somewhat unexplored. It appears as though they are complimentary processes, with predictions being used to anticipate an event boundary, and yet they appear to have different effects on memory and learning. Prediction error has been reported to have a beneficial influence on memory recall (Frank & Kafkas, 2021), while event segmentation is seen to have a negative influence on memory recall (Pettijohn & Radvansky, 2016). It is unclear how these processes would interact under a new context, being route learning.

With these aims in mind, we wanted to explore how well participants would learn a sequence of images depicting a route through an apartment. When viewing this sequence, there would be skipped images in the sequence for participants to identify and respond to, assessing how well they have learned the route through the apartment. To compare the effects of event segmentation, one of the routes depicted would have a high segmentation focus, showing images highlighting doorways between spaces, and the other route would have low segmentation focus, with no images highlighting the doorways between spaces. Comparing participants performance between routes should inform us on the role of event segmentation in route learning.

With previous research suggesting that prediction error can have both positive and negative effects on memory performance, and the novel approach of combining prediction error and event segmentation in a route learning experiment, we have opted for a non-directional hypothesis due to the exploratory and novel approach of this experiment.

Based on these aims and the previous work on the topic, we had the following hypotheses:

- H_1 : There would be a significant difference in participants ability to identify skips in a sequence of images, based on whether the sequence had a high or low focus on event segmentation.
- H_2 : There would be a significant interaction between the level of disruption to expectations and the level of focus on event segmentation, influencing participants ability to identify skips in a sequence of images.

4.2 Experiment 5 Methods

4.2.1 Participants

Sixty adult participants were recruited, from the University of East Anglia, using the School of Psychology's Research Participation Scheme. The experiment was also advertised on the participant panel platform Prolific (www.prolific.co), allowing for participants to be recruited from outside of the University of East Anglia. The experiment was carried out online, as such, online participant platforms were deemed the most appropriate methods of recruitment. Students were offered course credits for the completion of the study, while a rate

of £7.50 p/hr was offered as compensation for completion of the experiment for those recruited through Prolific. Ethical approval was received from the School of Psychology for all experiments.

4.2.2 Design

The experiment was a change detection task, where participants were asked to identify where a learned route is altered through skips in the sequence. There were two independent variables in this experiment. The first of which was levels of prediction disruption, which consisted of small and large disruptions, which was operationalised by introducing ‘skips’ in a sequence of images that appeared to show an individual moving through a series of rooms. These skips could be small (i.e., one image skipped in the sequence) or large (i.e., two images skipped in the sequence). The second of the independent variables was the route focus on event segmentation, where there was either low or high focus on event segmentation, which were manipulated by the focus of the images in the sequence, whether the images presented showed doorways and transition images between rooms (Figure 4.1) or not (Figure 4.2).

The levels of prediction disruption variable was influenced with every loop of the route, where the skip was randomised to come at any point in the loop, and whether it was one or two images skipped was also randomised to mitigate fatigue or learning effects, as the unpredictability of the skips required consistent focus. The route focus however, was manipulated in blocks,, with 12 loops of the sequence making up a block. The blocks alternated between high and low event segmentation focus so the participants would not become overly familiar with one set of images, and in combination with the random nature of the skips, learning effects were mitigated.

The dependent variables in the experiment were the number of correct identifications of skips in the sequence, as well as the number of false positives made throughout the experiment. When there was a skip in the sequence, participants had to identify the skip by pressing a button on the keyboard on the presentation of the next image. If participants do this successfully, it was considered a successful identification. If participants did not respond to a skip in the sequence, it was considered a miss, and if participants responded when there was no skip in the sequence, it was considered a false alarm.

Figure 4.1

Example Of the Route with High Event Segmentation Focus

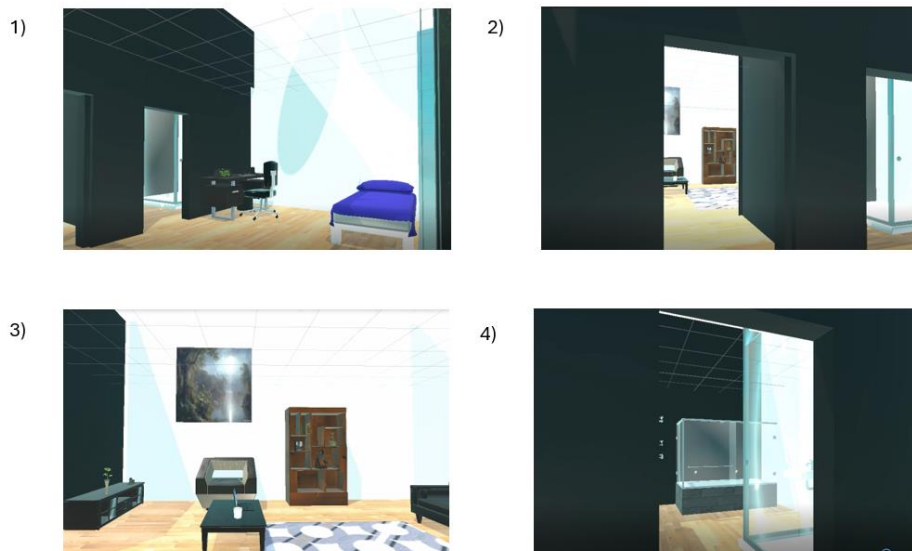
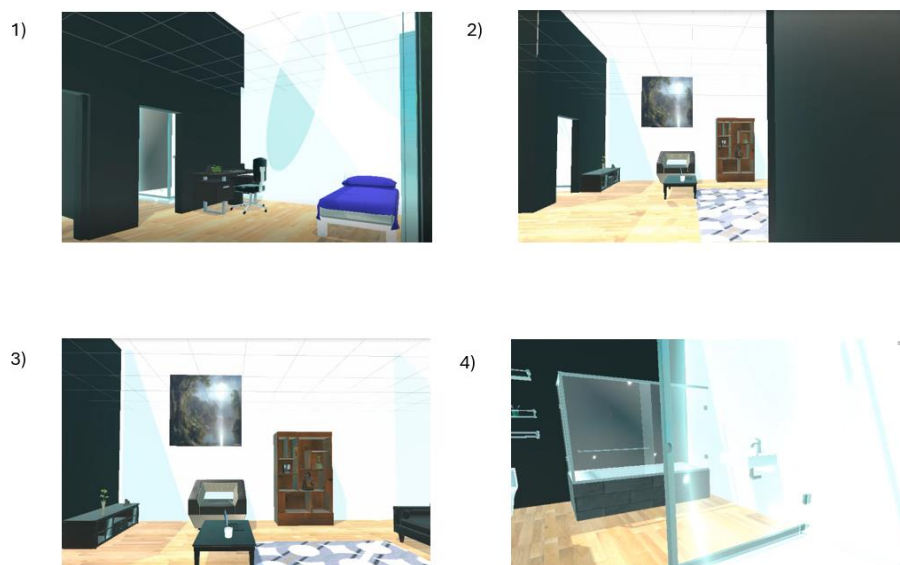


Figure 4.2

Example Of the Sequence with Low Event Segmentation Focus



4.2.3 Materials and Apparatus

Participants could use any computing device to complete the experiment as long as it had a keyboard, as the method of identifying skips in the sequence was mapped to specific keys. As a result, it was highly recommended for participants to use a laptop or desktop computer.

Unity was used to build the environment in which the route was recorded in. An apartment was built using objects either downloaded from the Unity Asset Store or created by the researchers themselves in Unity and Blender. A screen recorder was then used to record a researcher walking around the apartment environment using a VR headset. Screenshots were then taken from this video and used as the stimulus images for the routes throughout the experiment. Twelve screenshots were taken from the environment focusing on the rooms, which made up the low segmentation focus sets, and twelve screenshots were taken for the high segmentation focused set, alternating between doorway and room images. Each area of the apartment was represented by 2 images each. Gorilla was used to create and run the experiment, using the software's inbuilt experiment builder to sequence the trials, randomise the conditions, and develop the template for the experiment. SPSS was used for data processing and statistical tests, while JASP was used to carry out any Bayesian analysis, the data was reformatted in Excel and imported into R Studio for the creations of data visualisations and graphs.

4.2.4 Procedure

Upon starting the experiment, participants were greeted by a video of the researcher explaining details of the experiment, such as the task and duration of the overall experiment. Following this video, participants were then given a practice example using playing cards (Figure 4.3). Cards were shown one at a time, in sequential order from Ace to 8, which was then repeated. The sequence of cards was shown three times, and on the second and third loop either one or two of the cards were skipped. Participants were asked to identify a skip in the sequence as quickly and accurately as possible by pressing the spacebar. If a skip was correctly identified, a CORRECT message was briefly displayed before the sequence continued; if a skip was missed, a MISS message was displayed, instead; if participants

indicated there was a skip when there in fact was none, an INCORRECT message was displayed.

On completion of the playing cards example, participants were shown a video of a camera moving through a virtual environment of an apartment, walking through all the rooms in a specific route. Participants were instructed to attend to and learn the route in the video. The participants began the test trials, where a sequence of still images, extracted from the video 'walk through' were shown to participants. The route was shown in full two times without any skips so participants could familiarise themselves with the sequence of images. After the two full trials, skips were introduced, where participants would have to identify when there were skips in the sequence by pressing the space bar on their computing device. There were ten skip trials per block, making for twelve trials per block total. The images were presented on the screen for 1000ms, the blank screen in between images were on the screen for 500ms, and the feedback screen informing the participants if they made a correct or incorrect identification, or if they missed a skip, was presented for 100ms.

With the two independent variables (disruption to expectation and segmentation focus), all participants experienced both variables, as participants experienced four blocks of trials (alternating between low and high segmentation focus), consisting of 12 trials each, making 48 trials total. Each of these blocks had a mixture of one and two skip sequences; however, each block consisted of the same images, so the inclusion of doorways or not was consistent within each block. Therefore, there were two blocks with doorway images, and two without. The first two trials of each block contained no skips to remind participants of the route and to familiarise themselves with which condition the block was showing.

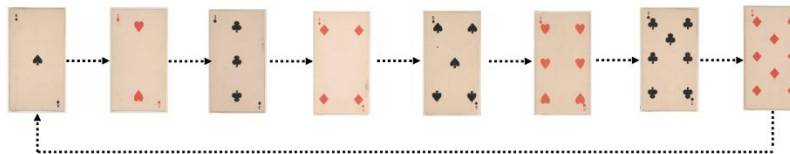
Between each block, an attention check was carried out. A shape was shown on screen for two seconds, and participants had to choose the correct shape out of a choice of three. If the attention checks were failed, a participant's data was discarded. Data was discarded if 50% or more of the attention checks were failed. After the attention check, a short video from the researcher would play, where participants were congratulated on their progress and encouraging them to take a short break before the next block began.

Figure 4.3

Training Example Provided on How the Sequence Order and Sequence Jumps Would Be Carried Out

In this experiment you will see a series of images – one at a time – in a sequence.

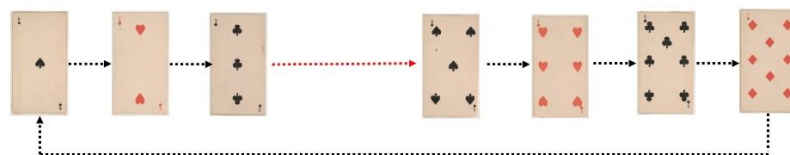
For example, see the sequence of cards below going from Ace of Spades to the 8 of Diamonds, and then looping back again.



You will see the image sequences repeatedly and look for when there is a change to the sequence.

As soon as you notice a change, press the *spacebar* as fast as possible.

For example, see the sequence of cards below.



The sequence goes suddenly goes from the 3 of Clubs to the 5 of Spades, skipping the 4 of Diamonds. When you see that 5 of Spades should not have been the next image, press the spacebar as quickly as possible.

4.2.5 Analysis

Due to using hit rate as a measure for this experiment, we also calculated the D Prime (d') and Criterion C (C) as outlined in signal detection theory (Macmillan, 2002). We were interested in d' as it is a measure for how sensitive participants are to changes in the test stimulus, thus highlighting participants ability to identify changes in the sequence. d' was calculated by calculating the differences in z scores between hit rate and false alarms ($d' = z(H) - z(F)$). Alternatively, C is a measure of how likely participants are to respond to stimulus, and C would be useful for determining how likely and often participants were responding to stimulus. C was calculated by finding the position of the midpoint between

$z(H)$ and $z(F)$ to assess a common shift reflecting a criterion change ($C = - [z(H) + z(F)]/2$) and paired with d' it provides an understanding in participants confidence in their ability to make judgements in the image sequence.

4.3 Results

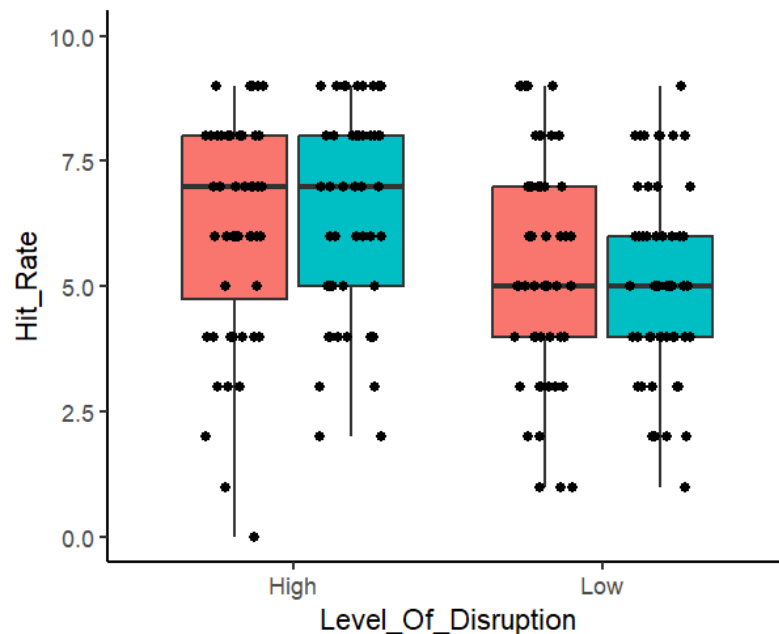
4.3.1 Pre-analysis Screening

Participants data was screened on completion of the study, where a maximum threshold of false positives was enforced as to not include highly influential outliers. The threshold for false positives was forty-eight, matching the total number of trials participants would experience throughout the entire experiment. As the participant would complete forty-eight trials in the experiment, exceeding this number of false positives would mean they were averaging one false positive per trial. If participants exceeded this number of false positives, their data was excluded. Along this criteria, eight participants were excluded, making for fifty-two participants overall. No participants were removed with the attention check screening.

Separate 2x2 repeated measures ANOVAs were used to assess the effect of disruption to predictions (low, high) and event segmentation focus (low, high) on participant's hit rate, d prime, and response bias (criterion c).

Figure 4.4

Average Hit Rate for Identifying Skips in A Sequence, By Level of Disruption to Prediction and Event Segmentation Focus



Note. Maximum Score per Block of trials was ten.

4.3.2 D' Prime

Results indicated that level of disruption to predictions had a significant influence on participants' sensitivity to the presence of a change in the sequence, where high disruption ($M = 1.34$, $SD = 1.65$), resulted in higher sensitivity to jumps in the image sequence, than low disruption ($M = .88$, $SD = 1.61$); $F(1,51) = 22.37$, $p < .001$, $\eta_p^2 = .305$. However, no significant effect was found for the route focus, with low focus on segmentation ($M = 1.22$, $SD = 1.48$), showing a lack of significant difference in the levels of sensitivity to change in the sequence as high focus on segmentation ($M = .99$, $SD = 1.79$); $F(1,51) = 1.13$, $p = .293$, $\eta_p^2 = .022$. Lastly, a significant interaction was found between the effects of route focus and level of disruption to expectations on sensitivity to changes in the sequence; $F(1,51) = 6.14$, $p = .017$, $\eta_p^2 = .107$.

As there was an interaction effect found between route focus and level of disruption to expectations on sensitivity to changes in the sequence, two further t-tests were carried out to

establish what was driving the interaction effect. When disruption to expectations were low, there was no significant difference for a high ($M = .90$, $SD = 1.88$) vs low ($M = .86$, $SD = 1.30$) segmentation focus; $t(51) = -.175$, $p = .862$, $d = -.02$, $CI = -.29 - .25$. However, when disruption to expectations were high, there was a significant difference for the low ($M = 1.59$, $SD = 1.56$) vs high segmentation focused trials ($M = 1.10$, $SD = 1.71$), $t(51) = 2.01$, $p = .049$, $d = .279$, $CI = .01 - .56$.

4.3.3 Criterion C

With Criterion C, 0 is considered the neutral value where the participant is considered to be unbiased to the noise around the stimulus. When $C < 0$, the participant is using more relaxed criterion for saying yes and is thus less confident in the accuracy of their responses. Meanwhile, when $C > 0$, the participant is using stricter criterion for saying yes, and thus is more confident in the accuracy of their responses.

Results indicated that level of disruption to expectations had a significant influence on participants criterion for response. High disruption ($M = 0.15$, $SD = 0.64$) resulted in stricter criterion for responding to stimulus than low disruption ($M = -0.08$, $SD = 0.49$); $F(1,51) = 22.37$, $p < .001$, $\eta_p^2 = .305$. However, no significant effect was found for the route focus, with low focus on segmentation ($M = -0.01$, $SD = 0.57$), showing similar criterion for response to stimulus as high focus on segmentation ($M = 0.08$, $SD = .059$); $F(1,51) = 1.17$, $p = .283$, $\eta_p^2 = .023$. Similar to d' , a significant interaction was found between the effects of route focus and level of disruption to expectations on participants criterion for responding to stimulus; $F(1,51) = 6.14$, $p = .017$, $\eta_p^2 = .107$.

As there was an interaction effect found between route focus and level of disruption to expectations on criterion to respond to stimuli, two further t-tests were carried out to establish the interaction effect. Unexpectedly, in comparison to the interaction effect in the d' results, the pattern of interaction is reversed with relation to C. When disruption to expectations were low, high segmentation focus ($M = 0.04$, $SD = 0.54$) resulted in stricter criterion for response than low segmentation focus ($M = -0.19$, $SD = .41$); $t(51) = .328$, $p = .016$, $d = .34$, $CI = .06 - .62$. However, there was no influence of route focus when disruption to expectations were high, where low segmentation focus used similar criterion to respond ($M = .17$, $SD = .65$), as

high segmentation focused trials ($M = .13$, $SD = .65$), $t(51) = .328$, $p = .745$, $d = .045$, $CI = -.22 - .32$.

Table 4.1

Means for Each Measure for Level of Disruption to Prediction Conditions and Level of Event Segmentation Focus Conditions

Measure	Disruption to Prediction	Event Segmentation Focus	
		High	Low
Hit Rate	High	6.31	6.48
	Low	5.42	5.12
d'	High	1.10	1.59
	Low	0.90	0.86
Criterion C	High	0.13	0.17
	Low	0.04	-0.19

4.4 Discussion

The current experiment aimed to investigate the influence of whether high or low focus on segmentation would impact our ability to correctly identify changes in a sequence of images, and whether large or small disruptions would make identifying changes easier. The results of this experiment suggest that while changing the level of focus on segmentation has some influence on performance, it is not a direct influence with a strong effect. This is highlighted through the results as no main effect was found for route focus in d prime or criterion c. These findings show that participants did not perform better or worse, had similar levels of sensitivity, and used the same criterion for response when the route focus was both high and low segmentation focused. However, we do see in the d prime and criterion c results that there is a significant interaction between route focus and size of disruption to expectation. With this interaction effect, we can see that route focus can have an influence on

how participants behave in these tasks, with changes to sensitivity to stimulus change and criterion for response having these significant interactions. However, perhaps the influence of route focus makes the changes in disruption size more evident, and high or low focus on segmentation has only a supportive role in influencing performance on this task.

We see that there is some influence of boundaries in the interaction effects, where there were significant interactions between route focus and size of disruption in the d prime and criterion c results. These results show that the influence of event segmentation is purpose specific, where the d prime results indicate that when participants are able to more effectively detect signal from noise, a focus on doorways reduces performance in comparison to the low segmentation focus performance. However, when participants are doubting their performance or struggling with a trial, doorways can act as a helpful aid for choosing to respond. This utility is highlighted through the criterion c results, where high segmentation focus lead to stricter criterion in comparison to low segmentation focus, specifically for the low disruption trial, where criterion for responding is not as strict as the high disruption trials. Event segmentation and boundaries appear to have more of an effect in confirming or denying hit choices, to parse out more ambiguous or difficult trials, while impeding performance in less ambiguous or easier trials. Route focus appears to have an informative role in this situation, where it interacts with size of disruption to change participants sensitivity to changes in the stimuli or changes how strict the criterion for response is.

The findings of this experiment can inform our understanding of the role of event segmentation in navigation and route learning. Research into the neural network composed of OPA (Kamps et al., 2016), the PPA (Park et al., 2011), and the RSC (Bilalić et al., 2019), suggest that these brain areas use boundaries in both global and local processing. Boundaries are used in global processing to divide distinct spaces, and in local processing by establishing a proximity relationship between the boundaries and local elements. In that case, we would expect that the high segmentation sequences would have produced better performance in the task, due to the higher focus of environmental boundaries in those images. Similarly, those sequences provided more global information, showing the transition between one space and the other, where we move between spaces and inform the overall route of the sequence. However, the interaction findings suggest that while boundaries are important to how these areas process information, they are not crucial for these areas to be able to be processed effectively, as demonstrated through the selective influence of boundaries as shown by the d

prime interactions. If boundaries played a critical role for navigation and route formation, we would expect that the high segmentation trials would have produced significantly better performance.

Alternatively, there is also an argument that we should have expected worse performance in the high segmentation trials. Research into event segmentation and memory highlight how crossing a boundary result in worse memory performance (Pettijohn & Radvansky, 2016), and this can even be seen when approaching a boundary or imagining crossing a boundary. While event segmentation may involve changes in memory performance for local information, or stimuli locked to a certain context or event, when we are looking at remembering a route and navigating a space, the influence of event segmentation is not as pronounced as we may have expected.

Alternatively, the findings of this experiment confirm what we understand to be the effects of prediction error. In the high disruption trials, participants were able to correctly identify changes in the sequence more often than in the low disruption trials. These findings show that the high disruption trials exceeded the threshold for prediction error more often, making changes in the route very apparent for participants. It is also in high disruption trials where we see an influence of event segmentation, as the d' prime for high disruption trials was influenced by whether there was a high or low focus on segmentation. This experiment placed a lot of importance on expectation, as participants were learning a route through an apartment via a sequence of images, if they are learning the route, they would know what to expect the next image to be. Seeing how expectation can be influenced by the focus on segmentation shows how prediction error and event segmentation share some commonalities. However, low disruption may not have been a large enough jump in the sequence to elicit a violation to expectations, resulting in a less accurate hit rate. The findings of this experiment support the findings of Bein et al., (2021), who found that violating expectations resulted in better memory performance, and we see comparable results here. Not only did participants have a higher hit rate when disruptions were larger, but their sensitivity to changes in the sequence and criterion for response changes too, with higher sensitivity and stricter criterion on high disruption trials. These effects are further compounded by whether there is a focus on segmentation or not, highlighting the connection between event segmentation and prediction error. High disruption resulted in participants being more aware of changes and more confident in their decision to respond. As reported by Greve et al. (2017), the stronger the

prediction error, the stronger the performance on the task, and we see that here, with the stronger prediction error in the high disruption trials resulting in higher hit rates, higher sensitivity to change, and stricter criterion for response.

Previously, the relationship between event segmentation and prediction error was discussed, where the processes were seen to be complimentary, where prediction error was seen as a part of event segmentation (Kurby & Zacks, 2008). However, in that discussion, event segmentation was seen to be a more involved process, taking account of other factors such as internal state, where prediction error was seen to inform event segmentation about context shifts. However, the results of this experiment do not portray the same relationship, and in fact, show an inverse relationship. Prediction error was shown to be a highly influential process in this experiment, producing main effects, whereas event segmentation seemed to inform decisions and play more of a supporting role to prediction error, as seen in the interaction results. The interaction results show in ambiguous trials, event boundaries support performance, while in less ambiguous trials, event boundaries impede performance. These findings suggest that our understanding of how these processes interact with each other may need to be further examined as these results contradict current understandings.

4.4.1 Future Research

While the current experiment provides a start to exploring the influence of event segmentation in navigation and route formation, there are some areas in which future research could improve upon to make findings clearer and reveal more about the influence of event segmentation in navigation and route formation. One limitation of this study were the levels of variables between conditions, only consisting of high and low for both segmentation focus and route disruption. One suggestion to improve upon this study would be to include more levels to both variables to highlight any of the current findings. For example, including larger disruption jumps may highlight an upper limit to the effect of prediction error on performance and behaviours. Similarly, including more levels of focus on event segmentation, such as a condition made up entirely of event boundary images, may draw out a significant effect of event boundaries, or if not, highlight that event segmentation does not play as large a role in navigation and route formation as we initially would have thought based on previous research into event segmentation and memory for spaces.

Another limitation, which is partially addressed in experiment six, is how certain are we that the current experiment showed the effects of event segmentation and prediction error on route formation and learning. In the current experiment, participants were required to identify changes in a sequence of images, however, that was the only task they were required to do. In future research it may be beneficial to include other tasks, such as organising the images into sequence order, or to draw the route through the space. The findings show that prediction error had a significant effect on performance in identifying changes in a sequence of images, however, there is room to improve the scope of this experiment, to include other measures to ensure we are testing route learning and formation, rather than just learning a sequence of images.

4.5 Experiment 6

The purpose of this follow-up was to ensure the measures we had created were testing what we wanted; that is, that participants were learning a route through an apartment and not just learning a sequence of images. As a result, we randomised the sequence of images, so they no longer followed a route. Differences in the results of this experiment and the previous one (Experiment 5) could be attributed to differences in route learning and sequence learning. We aimed to show that the results of the previous experiment were due to the influences of event segmentation and prediction error on route learning.

Based on these aims and results from the previous experiment, we had the following hypotheses;

- H_1 : There would be a significant effect of event segmentation on participants ability to identify skips in a sequence of images when the predictability of the sequence was low.
- H_2 : There would be significant differences in hit rate, d' prime and criterion c depending on route predictability, with low predictability resulting in significantly lower scores in the three measures than the high predictability of experiment 5.

4.6 Methods

Sixty adult undergraduate participants were recruited from the University of East Anglia, using the School of Psychology's Research Participation Scheme. Participants had a mean age of 19.78 years ($SD = 4.01$), made up of 43 female, 14 male, and 3 non-binary participants. Students were offered course credits for the completion of the study. Ethical approval was received from the School of Psychology for all experiments.

4.6.1 Design

The design for this experiment remained largely the same as the previous experiment, with the first IV examining the disruption to expectations, as manipulated through the number of images skipped per trial, where one level was one image skipped (low disruption), and the other was two images skipped (high disruption). The second IV was route focus having high or low focus on event segmentation, with one level showing images focusing on transition boundaries such as doorways (high focus), and the other level focusing on the room content (low focus). However, the order of the images was now presented out of sequence, thus testing route predictability with low predictability in this experiment being compared to the high predictability of the previous experiment. While the jumbled route did not follow the route of the video shown at the start of the experiment, the jumbled route was consistent across blocks, with the same number of images as the previous experiment, to ensure comparisons between the two experiments was as fair as possible. As a result of comparing results between experiment five and six, route predictability became a third IV, where predictability was manipulated through either presenting the images in the correct (high predictability) or randomised order (low predictability).

The dependent variables remained the same throughout this experiment, with the number of hits and false positives being measured throughout.

4.6.2 Materials and Apparatus

Participants were provided with a desktop computer in an isolated test room to complete the experiment. Unlike the previous experiment, participants were required to come into a lab and complete the experiment in person. The researchers were concerned that the

increased difficulty of the experiment would result in a large number of incomplete data sets if being completed at home without a researcher present.

All aspects of the environment and software use were all kept the same, with the only difference being the order in which the route images were presented. Image order was randomised, however, the same random order was presented to all participants.

4.6.3 Procedure

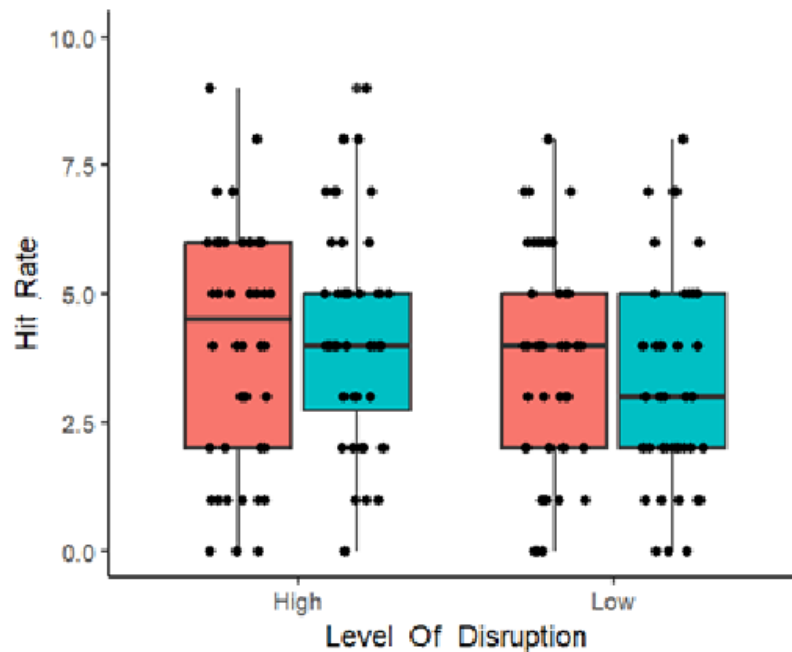
Procedure was kept the same as the previous experiment.

4.7 Results

Participant data was screened on completion of the study, where a maximum threshold of false positives were enforced as to not include highly influential outliers. The threshold for false positives was again forty-eight, matching the number of trials throughout the experiment. If participants exceeded this number of false positives, their data was excluded. Along this criteria, sixteen participants were excluded, making for forty-four participants overall. All remaining participants passed the attention checks.

Figure 4.5

Average Hit Rate for Identifying Skips in A Sequence, By Level of Disruption and Segmentation Focus, In A Low Predictability Sequence



4.7.1 D' Prime

Results indicated that level of disruption to expectations had a significant influence on participants sensitivity to the presence of a change in the sequence. High disruption ($M = -.25$, $SD = 1.57$) resulted in higher sensitivity to changes in the sequence than low disruption ($M = -.73$, $SD = 1.76$); $F(1,43) = 4.21$, $p = .046$, $\eta_p^2 = .089$. However, no significant effect was found for the route focus, with low focus on segmentation ($M = -.49$, $SD = 1.58$), showing similar levels of sensitivity to change in the sequence as high focus on segmentation ($M = -.49$, $SD = 1.78$); $F(1,43) = .004$, $p = .952$, $\eta_p^2 = .001$. No significant interaction was found between the effects of route focus and level of disruption to expectations on sensitivity to changes in the sequence; $F(1,43) = 2.07$, $p = .158$, $\eta_p^2 = .046$.

4.7.2 Criterion C

Results indicated that level of disruption to expectations did not have a significant influence on participants criterion for response, where high disruption ($M = -.04$, $SD = .66$) resulted in similar criterion for responding to stimulus as low disruption ($M = -.10$, $SD = .61$);

$F(1,43) = .279, p = .600, \eta_p^2 = .006$. Nor was a significant effect found for the route focus, with low focus on segmentation ($M = -.07, SD = .67$), showing similar criterion for response to stimulus as high focus on segmentation ($M = -.07, SD = .60$); $F(1,43) = .004, p = .952, \eta_p^2 = .001$. Finally, a significant interaction was not found between the effects of route focus and level of disruption to expectations on participants criterion for responding to stimulus; $F(1,43) = 2.07, p = .158, \eta_p^2 = .046$.

Table 4.2

Means for Each Measure for Level of Disruption to Prediction Conditions and Level of Event Segmentation Focus Conditions

Measure	Disruption to Prediction	Event Segmentation Focus	
		High	Low
Hit Rate	High	4.00	4.30
	Low	3.63	3.33
d'	High	-0.33	-0.17
	Low	-0.66	-0.80
Criterion C	High	-0.09	-0.01
	Low	-0.06	-0.13

4.7.3 Comparing Experiment 5 and Experiment 6 Results

To compare the results of the first and second experiment, 2x2x2 ANOVA's were used to assess the effect of disruption to expectations, whether high or low disruption, the route focus, whether high or low focus on segmentation, and route predictability, whether the image sequence had high or low levels of predictability, have on participants ability to identify changes in a set sequence of images. ANOVAs were carried out for hit rate, d' prime, and Criterion C.

4.7.4 D' Prime

Results indicated that level of disruption to expectations had a significant influence on participants sensitivity to the presence of a change in the sequence, with high disruption producing higher sensitivity to changes in the image sequence than trials with low disruption, $F(1,94) = 15.46, p < .001, \eta_p^2 = .141$. A significant main effect was also found for the predictability of the image sequence, with participants in the high predictability condition showing more sensitivity to changes in the image sequence than participants in the low predictability condition, $F(1,94) = 33.62, p < .001, \eta_p^2 = .263$. A significant interaction was found between the effects of route focus and the level of disruption to expectations on participants sensitivity to changes in the image sequence, $F(1,94) = 7.57, p = .007, \eta_p^2 = .075$.

However, no significant effect was found for route focus, where trials with high focus on segmentation elicited similar sensitivity to changes in the image sequence as trials with low focus on segmentation, $F(1,94) = .780, p = .379, \eta_p^2 = .008$.

As there was an interaction effect found between route focus and level of disruption to expectations on sensitivity to change, two further t-tests were carried out to establish the interaction effect. When there was high segmentation focus, low disruption to expectations ($M = 0.19, SD = 2.01$) resulted in a similar sensitivity to change as high disruption to expectations ($M = .44, SD = 1.85$); $t(95) = -1.79, p = .08, d = -.18, CI = -.54 - .03$. However, there was a significant influence of low event segmentation focus on sensitivity to change, where low disruption to expectations ($M = 0.10, SD = 1.70$) resulted in a lower sensitivity to change in comparison to when there was high disruption to expectations ($M = .78, SD = 1.73$); $t(95) = -4.95, p < .001, d = -.51, CI = -.96 - -.41$.

4.7.5 Criterion C

Results indicated that level of disruption to expectations had a significant influence on participants criterion for response, with high disruption producing stricter criterion for responding to the image sequence than trials with low disruption, $F(1,94) = 7.19, p = .009, \eta_p^2 = .07$. A significant interaction was found between the effects of route focus and the level of disruption to expectations on participants criterion for response to the image sequence, $F(1,94) = 7.57, p = .007, \eta_p^2 = .075$.

However, no significant effect was found for route focus, where trials with high focus on segmentation elicited similar criterion for response to the image sequence as trials with low focus on segmentation, $F(1,94) = .622, p = .432, \eta_p^2 = .007$. Similarly, a significant main effect was not found for the predictability of the image sequence, with participants in the high predictability condition showing similar criterion for response to the image sequence than participants in the low predictability condition, $F(1,94) = 1.57, p = .213, \eta_p^2 = .016$.

As there was an interaction effect found between route focus and level of disruption to expectations on criterion to respond to stimuli, two further t-tests were carried out to establish the interaction effect. A similar interaction effect was found for *C* as was found with *d'*. When there was high segmentation focus, low disruption to expectations ($M = -.01, SD = .57$) resulted in a similar criterion for response as high disruption to expectations ($M = .03, SD = .63$); $t(95) = -.65, p = .52, d = -.18, CI = -.17 - .09$. However, there was a significant influence of low event segmentation focus on criterion for response, where low disruption to expectations ($M = -.17, SD = .57$) resulted in a more lenient criterion to respond in comparison to the stricter criterion used when there was high disruption to expectations ($M = .09, SD = .64$); $t(95) = -3.98, p < .001, d = -.51, CI = -.38 - .13$.

4.8 Discussion

This experiment was interested in examining whether participants were learning a route and developing an understanding of the space portrayed in the route, or if they were just learning a sequence of images and the route aspect of the experiment did not matter.

In the *d* prime results, a significant interaction between route focus and size of disruption is no longer found on participants' sensitivity to changes in the stimulus. These findings suggest that participants may not have been reliant on event boundaries to make judgements between more ambiguous trials and were more so relying on the size of the disruption to the sequence. The implication of these results is that when the participants are not learning a coherent route, and learning a series of images, event segmentation does not inform how sensitive participants are to changes in the stimuli. This finding suggests there are differences with how the participants approached both experiments, and they resulted in

different forms of processing taking place. In the previous experiment, there was an interaction effect found throughout the results, suggesting that even if boundaries did not have a main effect, they were still having an influence on the size of the disruption effect. Here we see no influence of event segmentation on results, implying that in Exp 5 participants were not just learning a sequence of images, and instead engaging with the environment and learning the route on a deeper level than just the surface level of the image sequence.

Finally, with the criterion *c* results, there are no significant effect of any of the variables, nor is there a significant interaction. These results have significant implications for the argument of route learning in the previous experiment, as throughout this experiment participants did not change their criterion for responding to stimuli. Participants were not strict for their criterion for responding to stimuli, as the mean criterion *c* for each of the variables was less than 0. It appears that throughout the experiment, participants were not confident in their judgements, and so did not apply a strict or conservative approach to responding to the stimuli. An explanation for these findings is that the participants were learning a string of random images, where in the previous experiment they were learning a designated route through an apartment which made logical sense and they could follow along with.

While still being able to show main effects in hit rates, the *d* prime and criterion *c* results show they were making more false positives, as evident by the *d* prime being skewed towards false positives, and not being able to effectively identify changes in the route, as criterion for responding was not strict. This claim becomes more evident when we compare the findings from the previous experiment to this experiment.

4.8.1 Comparing Experiment 5 and 6

When we compare the results of experiments 5 and 6 together, we find that the predictability of the image sequence played a significant role in performance on the task. In terms of hit rate and *d* prime, there was a main effect of route predictability, with high predictable routes having higher hit rates and higher sensitivity to changes in the stimuli. These findings support the idea that the experiment was testing two different processes, with the original experiment testing processing with regards to route formation, whereas

Experiment 6 looked at sequence learning. With this in mind, we can see that prediction error plays a significant role in learning tasks, having a main effect in both the high and low predictability sequences. Similarly, event boundaries and segmentation play a role in route and sequence learning; however, it is not a significant role in itself, only interacting with size of disruption. These findings suggest that boundaries may inform our understanding of a route or sequence, and make changes easier to spot; however, they are not able to influence hit rates on their own. These findings highlight how event segmentation has effects other than the reported memory effects; however, they remain unclear due to a lack of research outside of memory research. Similarly, event segmentation interacts with other processes such as prediction error which can influence the strength of the effect, there are likely other processes affected by event segmentation which remain undiscovered.

Similarly, when we look at the d' prime results, participants in the high predictability condition had a higher sensitivity to changes in the stimuli than participants in the low predictability condition. Not only was there a significant effect of route predictability on hit rate, but participants were also able to tune out external noise and be more sensitive to changes they needed to identify, as evident by the lower rate of false hits in the high predictability condition. Once again, the implications of these findings are that participants engaged with the tasks differently depending on the predictability of the sequence. If the sequence followed a predictable and logical route, participants also had the focus on segmentation influencing their performance, emphasising the different ways participants were approaching the task. It is likely that participants in the high predictability condition were using boundaries to orientate and navigate themselves around skips in the sequence. This may indicate that the neural network consisting of the OPA, PPA, and RSC was being engaged with in this condition, informing participants of skips in the sequence, and being able to orientate themselves around the external noise of the correct images in the sequence. Whereas in the low predictability group, where there was no interaction with route focus, event segmentation did not inform how sensitive participants were to changes in the sequence, and it was solely focused on prediction error and the sequence of images, as opposed to learning a route throughout the apartment.

When we look at the comparison between criterion c scores, however, intriguingly, there is no observed main effect of route predictability, nor is there an interaction between route predictability and the other variables. When we look at the experiments in isolation, we

see different effect patterns where in Experiment 5 there was a main effect of size of disruption and a significant interaction between size of disruption and route focus, while in Experiment 6 there were no significant effects reported. Despite differences in the pattern of effects being present, it appears as though the predictability of the route did not have an influence on participants criterion for responding to stimulus. It appears as though throughout both experiments, participants utilised a similar level of strictness with regards to their criterion for response. The results of the criterion c comparison may require further exploration for a clear explanation of the observed effects.

4.8.2 Future Research

The current study served as a jumping off point for potential avenues of research surrounding event segmentation. In these experiments, we took the approach of looking at route formation and learning a route around an apartment, and tested participants on their ability to correctly identify changes in the route. This was only one approach of many which could be taken to expand our understanding of event segmentation. While this experiment touched on the concepts surrounding navigation, this was not a navigational task per se, which could also provide fruitful results into effects of event segmentation. For example, participants could be asked to navigate through a series of rooms and compare it to participants navigating through an open space or one large room. The process of event segmentation is not limited to memory, it is the process in which we divide our experience and a continuous stream of information. This experiment provided one example of how we can expand event segmentation into other processes. With that in mind, with this experiment aiming to examine event segmentation, there are a lack of main effects of focusing on segmentation. While we did find interaction effects, we expected to find main effects of route focus and yet this was not the case. Perhaps the method of testing was highly influenced by the prediction error component, and in the future, research should include a variety of measures which could develop a more holistic approach to the effects of event segmentation.

The need for further research into this area is particularly highlighted by the criterion c comparison between the two experiments. If route predictability can have no effect on the strictness of criterion to elicit a response, despite different effect patterns being reported within each experiment, this is cause for further examination. Perhaps changing the sequence of images may be a good place to approach this issue, using a larger sequence of images so

participants will need to be more selective with their responses, or alternatively, having more than one skip per sequence so participants may need to be more liberal with their responses. Along those similar lines of altering the sequence of images, it may be worthwhile for future research to use images with larger contrasts in the content to make the events and their segments more explicit. In the current experiments, while the rooms were different in terms of function and layout, they had similar aesthetics with the same wall and floor colours which may have resulted in the segmented nature of the apartment being reduced. This could potentially explain the lack of route focus main effects, but that cannot be confirmed without further research into the area. The criterion results do not have a clear explanation currently, however, that offers the opportunity for further research to enhance our understanding of the results of this experiment.

When considering the findings and implications of the work in this chapter, it is important to consider an important limitation in that experiment five was completed online while experiment 6 was completed in person. The difference in testing condition may cause some to question the validity of comparing the findings of these two experiments. However, the experimental design was identical otherwise, using the same stimulus, number of trials, with experiment six using a randomised order for the images. This was deemed to be a necessary limitation to take on, due to the increased difficulty of experiment six, we were concerned completion rates would fall dramatically if we carried it out as an online study. In future research it would be ideal to either complete both experiments either online or in person, however, to ensure we had enough data to meaningfully compare, this change in experimental procedure was an important change to make.

4.9 Conclusion

The current study aimed to look at the effect of prediction error on route formation and provides a strong basis of evidence for the effect of prediction error on route and sequence learning. Higher levels of prediction error result in increased sensitivity to changes in the sequence, and a stricter criterion for responding to stimuli. This study also aimed to analyse the effect of event segmentation on route formation, and results highlighted some key points to consider. While there was no main effect of route focus, it often had an interaction effect with size of disruption. While the lack of main effects does not concretely show event segmentation having a key role in route formation, the interaction between event

segmentation and prediction error provides new insights into the relationship between the two processes. Before, the two processes were thought to be complimentary with prediction error being a factor in event segmentation. The results of this study show that this may not be the case, and that event segmentation can have an informative role in the effects of prediction error. These findings raise the question of how event segmentation interacts with other cognitive processes, as up to this point, event segmentation has often been studied in isolation, but this study provides evidence that event segmentation can influence and be influenced by other processes.

To better understand the implications of these results, future research should develop different measures for assessing the role of event segmentation in other contexts other than memory research. While this study was a starting point, there are improvements which could be made on its design which could be more enlightening, such as the use of multiple measures in an experiment. The results as they currently stand do not provide a thorough explanation as to the effect of event segmentation on route formation, but they show there is an influence. With further research into the area, it could become clear the exact role that event segmentation can have in route formation.

**Chapter 5 –
Exploring how and why we segment**

Chapter 5 – Exploring how and why we segment

5.1 Introduction

The project up to this point has largely focused on the consequences of event segmentation, and has tried to establish a way of empirically testing and highlighting the effects of event segmentation on memory. While this approach has produced some notable findings, there was often ambiguity in the results. However, there looked to be a trend of when the segment was more prominent, or when participants were made more aware of the differences between spaces, significant differences in memory performance would emerge. In particular, free recall improved while recognition worsened with more prominent segments. Thus, the question of *how* we segment spaces becomes important. If the previous results in this project suggest that the effects of event segmentation are dependent on the strength of the segment, research should then investigate how individuals segment spaces, and what we view as important information in strengthening our event segments.

Previous work, cited in this thesis, has investigated the effects of event segmentation (Pettijohn & Radvansky, 2016; Logie & Donaldson, 2021; Buckley et al., 2022), but comparatively little has focused on *how* we segment spaces. One of the most popular areas of research into event segmentation is the idea of doorways causing forgetting (Radvansky, 2012; Radvansky et al., 2015; McFadyen et al., 2021). This work has produced findings exploring memory differences in different age groups (Radvansky et al., 2015), the effect of walking through a doorway on memory performance (Negen et al., 2020), the effect of imagining walking through a doorway on memory performance (Lawrence & Peterson, 2016), and so on. However, in all these experiments it is assumed that environments are segmented in the same way and that there is little variation in what humans use as information to segment spaces. While there has been research exploring segmenting videos (Cutting, 2014), or book passages (Newberry & Bailey, 2019), the same level of research has not explored if how we segment spaces is the same and as universal as those other mediums. This raises the question of how do we segment space?

5.1.1 Individual differences in segmentation

When it comes to analysing the effects of event segmentation, differences in participant performance are often attributed to differences in the environment, or else

sometimes categorised as noise affecting the participants. While research does suggest that there is a high level of cohesion between when participants make segments (Sasmita & Swallow, 2023), as well as a neural basis to event segmentation (Yates et al., 2022), more work could be done to understand the variance in individual abilities to segment information. Some work exploring variance includes exploring age differences, where younger adults are reported to have more hierarchical segmentation organisation in comparison to older adults (Kurby & Zacks, 2011), and exploring segmentation ability, and how it uniquely explains variance in event memory, and this effect was found strongly in both older and younger adults. Additionally, some research has found participants segmentation ability were in line with experts in the subject, even when unfamiliar with the subject being watched. The only difference between experts and novices were segmentation grain was found to be more coarsely grained and imprecise in novices (Levine et al., 2017). If our ability to segment is intuitive, then the prior knowledge on a topic should not result in variety and imprecision in segmenting.

However, an area which has been underrepresented in understanding segmentation ability is research into the development of event segmentation in children. When segmentation ability with children and adults are compared, children show a large variance in segmentation ability, with more unfocused or coarse segments being made in comparison to adults (Benear et al., 2023). The number of segments and the general location of segments is consistent with adults, highlighting that there may be a refinement in segmenting ability with age, however the core mechanisms are in place from a young age. While evidence suggests segmenting ability refines with age, the development of these refinements is largely unexplained due to a lack of exploration into the differences in segmenting ability. By understanding what parts of the process are innate and which change with time, we would gain a greater understanding into how we segment information, and how we interact with the space around us as we grow older.

The issues of understanding the development of event segmentation were highlighted by Duncan and Finn (2025). In this work, they raise concerns about the methods of testing event segmentation in children, such as verbal ability to express memories being recalled, as well as attention in event segmentation tasks. These methods may result in a lower quality of response or difficulties with interpretation due to potential issues with children's verbal and attention abilities. They also note that the findings discussed previously of segmenting ability

being coarser in children, and how these findings are at odds with event segmentation theory. In particular, event boundaries are created when event models held in working memory fail to predict ongoing events, and one would expect children's event models to poorly predict ongoing events due to less real-world experiences and thus, less accurate expectations, resulting in more frequent event boundaries. However, this is not the case. While limitations in children's cognitive development, such as lack of predictive abilities, may offer an explanation for differences in segmenting ability, it is difficult to make this claim due to the limitations in testing children's segmenting abilities. Children may not have weaker segmentation abilities, but different abilities. The coarser segments suggest that there are more individual differences and idiosyncrasies with how children segment perhaps due to fewer life experiences. Yet, there has been little research focused on understanding how these segments refine and become less idiosyncratic. Not fully understanding the development of segmentation abilities from childhood to adulthood is creating a gap in the literature, and understanding how these processes change with time and refine may prove useful in understanding the effects of these segmentation processes.

Often when examining event segmentation on a brain structural level, the OPA, PPA, and RSC are cited as a neural network responsible for how we segment spatial information, being responsible for the perception of environmental boundaries, local information, and the integration of prior knowledge (Bilalić et al., 2019; Henriksson et al., 2019; Oettringer et al., 2025). However, these cortical areas are not fully understood. While these areas are important in event segmentation involving spatial navigation, we do not only encounter event segmentation with spatial navigation, but also segment written information, visual and auditory information such as movies (Cutting, 2014), and text (Newberry & Bailey, 2019), which would not involve the RSC. In all circumstances of event segmentation, memory is the core component as it organises and consolidates a continuous stream of information, and so, the hippocampus and neural networks involving the hippocampus would be instrumental in our ability to segment information. The hippocampus shows a high level of individual variance affecting memory performance, from autobiographical information (Palombo et al., 2018), to semantic information (Klooster et al., 2020), and spatial and topographical information (Hartley & Harlow, 2012). Within the realm of event navigation, some research into hippocampal activation has revealed how complex this process can be. In one study, it was found that while the prefrontal cortex consistently responds to detours and prediction error, as previously discussed a very integrated process with event segmentation, the

hippocampus does not (Spiers & Gilbert, 2015). Additionally, the variability in hippocampal and parahippocampal cortex activation was found to be modulated by both aesthetic and spatial qualities of the stimuli (Gregorians et al., 2026). Understanding this process from a neuroscience perspective can guide how we should approach the topic from a behavioural perspective, and more work into these areas would be able to inform research into event segmentation moving forward.

While this experiment does not aim to test children's segmenting abilities or examine event segmentation from a neuroscience perspective, highlighting the work in these areas inform the aims of these studies. There is still a lot we do not understand about how we segment information and the individual perspectives of segmenting, and so this experiment aims to address that issue. By focusing on how people segment information, asking them what was important in their segmentation judgements and how confident they are in their assessments, we may gain an insight into how these segmentation behaviours manifest, and may inform these areas of research in where to begin examining how segmentation behaviours manifest with age and time.

5.1.2 Making sense of unclear environments

Throughout this project, a point of discussion has been the importance of test environments when researching event segmentation. Namely, discussing how seminal research into event segmentation has often used simplistic or empty rooms and environments (Radvansky & Pettijohns, 2016; Radvansky & Pettijohns, 2018). This issue is of concern due to the complexity of environments in the real world. While the original EHM addresses some complexities of environments, such as shared elements in a space and competitive stimulus, empirical research has not been conscious of how the complexities of a space affects event segmentation. This is an important issue which needs to be addressed, as there is research to suggest more complex environments or difficult to traverse environments have significant effects on memory performance and navigation abilities in those spaces. For example, He et al. (2021), investigated spatial learning in a number of environments, each of different levels of difficulty. They tested for observing spatial relationships between locations of interest in the environment. They manipulated difficulty by utilising VR to change the visibility of different buildings in the environment, and they found that participants who had a higher reported sense of direction performed better in low visibility environments, in comparison to

those with low sense of direction; however, there were no differences between participants spatial learning ability in high visibility environments. These results suggest that spatial learning differences are dependent on the spatial integration difficulties. This experiment highlights how some differences in memory and spatial performance are contingent on the difficulty of the spaces being learned. Findings like this highlight the importance of considering the role of the environment being tested, not only the role of doorways or traversal methods between spaces, but also the spaces themselves-

The complexity of environments can also affect how we engage with spaces on a neural level. Bilkey et al. (2017) found that participants who experienced prolonged exposure to complex environments showed increased selectivity of place cell activation in comparison to a control group. Furthermore, fewer place cells in the complex environments group expressed high levels of Arc protein, a marker of recent activation, following brief exposure to a completely novel environment. Here, we see that long term exposure to complex environments can result in differences in neural activation and cortical structure, changing how the brain responds to environments, and being much more selective in what is registered as a novel environment. This experiment highlights both the importance of consideration for the complexity of spaces, as well as the previously discussed individual differences in event segmentation, as the previous chapter discussed the role of place cells in event segmentation. With neural activation differences dependent on exposure to complex environments, as well as in moment differences in spatial learning, there are numerous avenues which must be explored further to develop our understanding of event segmentation and memory performance.

Finally, familiarity and knowledge of a context has an important mediating role when it comes to event boundary response, and participants knowledge of a context can influence their event memory. Pitts et al. (2021) examined both younger and older adults in tests of episodic memory for videos of activities that may or may not be familiar for that age group. Age related differences emerged in event segmentation ability and memory performance only when older adults lacked semantic knowledge, viewing activities they were unfamiliar with. When provided with relevant semantic knowledge, they performed similarly to younger adults. This is an important finding as despite semantic and episodic memory being different memory systems, these findings highlight their interdependence, and how familiarity with a task or activity may mediate event segmentation related memory effects. Similarly, van de

Ven et al. (2026), found that when a familiar context was created through the use of sound cues while presenting images to participants, participants showed increasingly faster boundary response times for each repetition of the sound context, compared to novel contexts. These studies highlight the novel role of familiarity with regards to event segmentation, where participants do not need to have experienced an event for themselves, but be familiar with the context of an event for familiarity to aid with encoding and retrieval of event memory. And so, it would be useful to explore what it is about familiarity that improves a participants event memory, is it a factor they are conscious of, or is it altering how they engage with the space altogether? It is an important factor to understand not only for its effects on segmentation ability, but for how it may change how a participant engages with the stimuli in the first place.

5.1.3 Aims and objectives

There are two main aims of this experiment. One aim is to determine what factors are perceived by participants to be important when making segmenting judgements. How participants perceive and make sense of an environment could be an important part of understanding the individual experience when we segment information. Perception is critical in the processing of information and little research has explored participants views and thoughts on an environment. This experiment will use qualitative measures to explore participants thoughts around why they segmented information the way they did. Using qualitative methods will allow for a rich account from participants on what they believe is influencing their ability to segment and what prompted them to segment the spaces in the ways that they did. Research into event segmentation needs more exploratory experiments to expand our understanding of the cognitive processes behind event segmentation. This work may help reveal factors that influence cognitive processes behind segmentation judgements. If there are differences in how an environment is perceived, it could result in differences in how an environment is segmented.

The first hypothesis proposed for this experiment is:

- H_1 : Participants will perceive clearly defined spaces differently to less clearly defined spaces. These differences in perception will result in different perceived segmenting abilities across environments.

While we aim to explore participants' perceptions of the spaces, we also aim to look at differences in memory performance. The effects of event segmentation on memory have rarely been explored in ambiguous spaces, where participants would have to segment the spaces themselves and use their own generated segments in exploring and learning the environment. It is in these spaces we would likely see a higher influence of event segmentation, as demonstrated in the research by He et al. (2021), which demonstrated the variable influence of event segmentation depending on the perceived difficulty of learning the space. While He et al. focused on levels of visibility in altering the difficulty of a space and only looked at learning an environment, this research is taking a different approach to difficulty and perception. Ambiguous spaces would result in a perceived variability not only in the difficulty of learning the space, but also segmenting the spaces into discrete segments. As a result, a second proposed hypothesis for this experiment is:

- H_2 : Participants will have a better memory performance for the spatial layout and objects in a scene when scenes are lower difficulty than when spaces are higher difficulty.

5.2 Methods

The study was split into two parts. In part one, participants explored two environments using VR, were asked to draw maps of the spaces they explored, and then answered questions about the maps they had drawn. The second experiment was carried out online, a different set of participants rating the maps drawn by the first set of participants on five different accuracy measures.

5.2.1 Participants

For the first part of the study, thirty adult undergraduate participants were recruited from the University of East Anglia, with a mean age of 20.5 years ($SD = 4.61$ years), made up of 19 females, 9 males, and 2 non-binary participants. Participants were recruited using the School of Psychology's Research Participation Scheme. Students were offered course credits for the completion of the study.

For the second part of the experiment, participants were recruited from the online participant panel platform Prolific (www.prolific.co). Recruiting from Prolific ensured that there was no crossover in participants. Participants were offered a rate of £7.50 p/hr as compensation for completion of the experiment. As participants were only rating the maps drawn by participants from part one, and not providing any information of their own, they were acting more so as raters as opposed to additional participants. As a result, demographic information was not collected for this group of participants to follow the Information Commissioner's Office (ICO) GDPR data protection principle of data minimisation (ICO, 2024). It was deemed unnecessary to collect demographic information for these participants as they were grading the maps of other participants, and so their demographic information was not relevant to the purpose of the study, and the information provided is adequate without it.

Ethical approval was received from the School of Psychology for the experiment.

5.2.2 Design

For part one of the study, the dependent variables were the maps drawn by participants upon completion of exploring the virtual environments, as well as the written answers they gave to the questions about their maps.

In contrast, the dependent variables for part two were five different measures of accuracy given to the maps drawn in part one including the number of objects, number of walls, object size, object location, and wall location. Participants were shown a map drawing alongside a screenshot of the environment, and participants had to rate the accuracy for all five measures. As the maps were rated and given quantitative scores by the second set of participants, the data was analysed using a series of t-tests. However, due to the qualitative nature of the written responses to the questions about the maps, the data was analysed using thematic analysis.

The independent variables for both parts of this experiment were the familiarity of the environments being presented, whether they were high familiarity (an apartment) or low familiarity (an art gallery) spaces (Figure 5.1). For this experiment, familiarity was assessed by how likely you are to encounter these spaces in everyday life, you are likely to encounter

and therefore be more familiar with, a living space as opposed to an art gallery, which would be a much more rare occurrence. In He et al. (2021), difficulty in learning was influenced by visibility of learning environment, and here we have assessed difficulty with familiarity of the space, where participants would have more schemas in place and prior experience learning a more familiar space, like a living space, as opposed to an art gallery, which they would have less real-life experience with. Familiarity was assumed to be higher for the apartment and less for the art gallery. For part one, this was whether they were exploring and drawing maps for an apartment or an art gallery. For part two, participants rated both conditions, however, the blocks the conditions were presented in were randomised. For part two, participants assigned accuracy ratings for map drawings of both environments that the participants explored, with the sequence of maps being randomised for participants.

Figure 5.1

Environments explored in experiment



Note. A bird's eye view image of the apartment environment (Left) and the art gallery environment (Right) explored in the experiment.

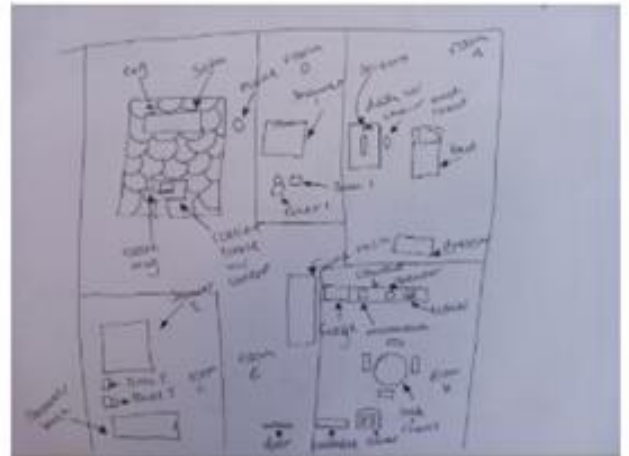
5.2.3 Materials and Apparatus

There were two virtual environments for participants to explore, consisting of a large space with a series of items arranged around the space. In one environment, the objects and layout were reminiscent of an apartment without interior walls, with objects indicating the space was made up of a living room, bedroom with ensuite, kitchen and bathroom. In the second environment, the objects and layout were reminiscent of an art gallery without interior walls, with objects indicating the space was made up of a painting gallery, a statue gallery, a café, and a storage room. The environments were developed using Unity, with objects being either downloaded from the Unity Asset Store, or built by the researchers using Blender.

An HTC Vive Head Mounted Display (HMD) was used, along with HTC motion trackers, which enable participants to freely walk around and have their movements fully and accurately represented in the virtual environment. The VR environment was run through a customised PC, which was a customised HP Z4 G4 workstation, with 64GB RAM and an Intel Core i9-9920X CPU, consisting of 12 cores and 24 threads with clock of 3.5 GHz. The CPU could run games with frames per second ranging from 151.1 to 335.1 FPS depending on the settings. As we wanted to provide as smooth and consistent running rate as possible, we prioritised performance to ensure there would be as little lagging or dropped frames as possible. Framerate was capped at 60 FPS to prevent variations in framerate. Participants drew maps using a pencil and an A4 piece of paper, which were later scanned and uploaded to the researcher's computer. A Dell laptop was provided with a questionnaire created using Gorilla Experiment Builder being presented to participants to answer questions about the maps they had drawn.

In part two of the experiment consisted of an online questionnaire hosted on Qualtrics, and included three measures, where participants had to rate on a sliding scale the accuracy of the size and location of the objects, and the locations of the walls on the drawn maps, with 1 representing not accurate, and 6 representing very accurate (Figure 5.2). There were two additional measures where participants had to rate the number of objects and walls, with -3 indicating a lot missing from the drawn map, and +3 indicating a lot of additional objects present on the map. The drawn maps were presented along a bird's eye view screenshot of the maps with walls present in the environment.

Example of Rating Question in Part Two of the Experiment



Not accurate 1 2 3 4 5 6 Extremely accurate

-3 -2 -1 0 1 2 3

Some missing Some extra

5.2.4 Procedure

For the first part of the experiment, participants arrived at the VR lab in the UEA School of Psychology, where they met the researcher. Participants were given an explanation of the experiment and what would be expected of them, and then given the opportunity to ask questions. Following this briefing, participants were placed in the first virtual environment, where they were given five minutes to walk around and explore the space. Participants were then brought to a table where they were given a pencil and paper given ten minutes to draw a bird's eye view map of the environment they had explored. When the drawings were completed, participants were asked to break up the map into as many or as few rooms as they thought were present by inserting walls into their completed maps by drawing in where they thought walls would separate the spaces, and then label the rooms they had created. Once completed, participants were then instructed to answer two questions on a laptop: 1) "What factors were important in your wall placements", and 2) "Did anything seem out of place". When the participants had completed the questions on the laptop, they were given a short break before completing the same tasks for the second environment.

For the second half of the experiment, participants began the rating task, where a map drawing was shown alongside a screenshot of the environment the map was drawn of. Participants had to rate the maps on five measures of accuracy, giving a rating for the location of walls, location, and size of objects on a scale of 1 – 6, and the number of objects, and walls present in the map drawing, on a scale of -3 - +3 The drawings were presented in six blocks of ten, where each block was grouped by familiarity types (i.e., a block would be made up solely of high familiarity or low familiarity maps). The order of the blocks was randomised to reduce practice or fatigue effects.

5.3 Results

5.3.1 Object Ratings

A repeated measures t-test indicated that there was not a significant difference in accuracy ratings for the size of objects on drawn maps of high and low familiarity environments by independent raters. Raters found that the size of objects in high familiarity environments were drawn to with a similarly accurate size representation ($M = 2.57$, $SD = 0.54$), as the size of objects drawn on the low familiarity environment maps ($M = 2.38$, $SD = 0.55$); $t(29) = 1.29$, $p = .208$, $d = 0.24$, $CI = -0.22 - 0.50$.

Similarly, a repeated measures t-test indicated that there was not a significant difference in accuracy ratings for the location of objects on drawn maps of high and low familiarity environments. Raters found that the objects drawn on maps for high familiarity environments were of a similar representation of the objects location in the explorable environment ($M = 2.27$, $SD = 0.52$), as where objects were drawn to be on the low familiarity environment maps ($M = 2.00$, $SD = 0.54$); $t(29) = 1.96$, $p = .06$, $d = 0.36$, $CI = -0.01 - 0.56$. It should be noted that this t-test was marginally non-significant, and would still be worth considering in future research, as an effect could be present with a slightly different experimental design or n .

Finally, an independent t-test indicated that there was no significant difference in accuracy ratings for the number of objects on drawn maps of high and low familiarity environments. Raters found that there were a similar number of objects represented on the drawn maps for high familiarity environments ($M = -1.19$, $SD = 0.79$), and low familiarity environments ($M = -1.27$, $SD = 0.73$) in relation to the number of objects present in the explorable environments; $t(29) = 0.39$, $p = .70$, $d = 0.07$, $CI = -0.34 - 0.49$.

5.3.2 Walls Ratings

An independent t-test indicated that there was a significant difference in accuracy ratings for the location of walls on drawn maps of high and low familiarity environments. Raters found that the walls drawn on maps for high familiarity environments were more accurately representative of the walls locations in the explorable environment ($M = 2.20$, $SD = 0.52$), as opposed to where walls were drawn to be on the low familiarity environment maps ($M = 1.72$, $SD = 0.41$); $t(29) = 3.54$, $p < .001$, $d = 0.65$, $CI = 0.20 - 0.76$.

An independent t-test indicated that there was also a significant difference in accuracy ratings for the number of walls on drawn maps of high and low familiarity environments by independent raters. Raters found that the number of walls drawn on the high familiarity environment maps were drawn to a closer number that was in the explorable environments ($M = -0.75$, $SD = 0.87$), as opposed to the number of walls drawn on the low familiarity environment maps in relation to the explorable low familiarity environment ($M = -1.40$, $SD = 0.84$); $t(29) = 2.94$, $p = .006$, $d = 0.54$, $CI = 0.20- 1.11$.

5.4 Qualitative Methods

5.4.1 Theoretical positioning

Our understanding of event segmentation and its role in how we remember spaces has largely been investigated using quantitative experiments (Radvansky & Pettijohn, 2015, Pettijohn & Radvansky, 2016; Pettijohn & Radvansky, 2018). This approach has been appropriate to measure participants memory performance when moving between segmented and open spaces. However, event segmentation is not a process isolated to memory performance, as how we segment experience, and our perception of spaces is an individualistic process. Our ability to segment spaces is based in past experiences of similar environments and information about spaces to construct schemas which influence what we perceive as an event (Sargent et al., 2013). Similarly, our experience of previous events informs expectations which allow us to make predictions about the flow of multiple events, and provide predictions which can be violated, where prediction error is high and segmentation is likely to occur.

Due to the importance of past experience and the role of the development of event schemas, exploring the individuals experience in segmenting spaces is fundamental to our understanding of event segmentation. Previous research provides a strong basis for understanding the consequences of event segmentation on memory performance (Radvansky et al., 2015; Pettijohn & Radvansky, 2016; Logie & Donaldson, 2021), but comparatively, little research has been carried out to understand the segmenting experience. As a result, this experiment included a qualitative approach. Upon completion of drawing their maps of the spaces and dividing up the maps into rooms, participants were asked two open questions

about their experience. These two questions were “What factors were important in your wall placements”, and “Did anything seem out of place”. The purposes of these questions were to understand what participants perceived as being influential in how they segmented the space and what was hindering their ability to make clear judgements about the space.

5.4.2 Ontology

Ontology is the study or consideration of the nature in which things exist and what is considered to be reality (Guarino et al., 2009). There are two ontological perspectives to be considered with regards to this experiment. The first is the realism perspective, which believes that there is an objective reality independent of human experience, where universal truths can be observed and measured (Jenkins, 2010). With this perspective, objective measures and information exist and is possible to achieve through appropriate research methodologies. Conversely, relativism is the second ontological perspective, that there is no objective reality, and there are numerous realities as valid and true as each other (Guba, 1992). Under this perspective, reality is constructed in the human mind, influenced by background, social norms, experience and emotions. As a result of this perspective on information, an objective reality is not knowable independently of subjectivity, and so understanding the subjective experience is necessary to understand the human perspective of reality.

While the relativism perspective does provide an interesting view on how we approach event segmentation, the current research adopted a realism approach. There are multiple reasons for the adoption of this perspective. For one, this research is being carried out as a part of a project consisting of several quantitative experiments, all under the framework of an established theory. A relativism approach would call into question using the EHM and event segmentation research as a framework for this project and would be a large departure from the rationale of previous work which would question the validity of previous findings. Second, participants all experienced the same conditions and environments, which were carried out under the novel experience of VR. With the use of VR, participants do not rely on previous knowledge due to the novelty of the experience, and so, all participants will have a similar new experience which are easily comparable. Under this methodology, a realism perspective is appropriate due to removing participants from a normal situation and providing them all a novel experience.

5.4.3 Epistemology

Whereas ontology is concerned with our perception of reality, epistemology is more so concerned with knowledge, namely what is knowledge, how is it acquired and what are the limitations of this knowledge (Code, 2017). As we are interested in how our knowledge of event boundaries and how we segment experience is developed for individuals, a constructivism approach was adopted for this research. Constructivism posits that knowledge is constructed based on an individuals experience and interactions with the world (Lee, 2012). Under this approach, a contextual reality exists, however, how one engages with this reality is individual specific, based on their own experiences.

With regards to event segmentation, this epistemological approach seems the most appropriate for understanding the segmentation process. Segmentation of space can be influenced by a number of factors involving experience (Schwan & Garsoffky, 2008), such as the spaces in which we grew up, the environments we frequent or spend most of our time in, as well as how often we traverse through multiple environments. For example, those who regularly traverse through multiple diverse environments are more likely to have a different construction of when environmental boundaries occur as opposed to someone who often remains in the same few environments. Similarly, those who grew up in an open plan home would have a different construction of environmental boundaries as opposed to those who grew up in more closed off spaces. Due to not being able to control for individuals experiences, but still interested in exploring how individuals engage with the same environments, a constructivist approach is the most appropriate.

5.4.4 Thematic Analysis

Combining ontological realism and epistemological constructivism presents a question on how to explore the ideas of segmenting space. These positions hold that there is an objective reality independent of human perception, and that we can measure this objective world, however, humans are not objective in engaging with this reality. Past experiences cannot be divorced from how we engage with the world, and it is important to reconcile that individuals will have different approaches to engaging with this world.

With event segmentation research, there has been a large focus on the objective consequences of crossing through event boundaries affecting memory performance. However, the world is not consistent in spatial layout or constructions. For example, how do we segment experience when we are outside, and not relying on doorways or physical boundaries in the environment. Our understanding of what information is important in segmenting environments is a neglected area of research. As a result, this experiment and qualitative analysis presents a novel methodology in the topic of event segmentation. With the variability of human experience, we cannot apply the consequences of event segmentation to all when there has been little research into understanding what we use to segment spaces.

As we want to understand individuals' responses to the same reality, thematic analysis was deemed the most appropriate methodology for these aims. Braun and Clarke (2006), highlight the utility of thematic analysis in psychological research, as this methodology offers an accessible yet flexible approach to analysing qualitative data. While being able to recognise the variability of human experience, we are interested in identifying and interpreting patterns of shared meaning, and to consolidate a commonality of themes and ideas across environments. With this approach, we do not expect participants to give the same responses, however, there may be similarities in the language used, the tonality of the responses, or in the message the responses want to convey.

However, with interpreting responses, it is important to clarify that a top-down or theoretical approach to the responses and analysis was used. Because this analysis is part of a larger project with an established theoretical framework, we are approaching the data with some assumptions and preconceptions of what themes we could expect. While the qualitative nature of this analysis is explorative in the topic of event segmentation, it was not possible to approach the responses in this experiment with a fully explorative coding system. We carried out the analysis with a research question in mind, and an expectation of what themes we may expect to see in the responses. However, this approach still allows the flexibility necessary to understand the nuances in how individuals segment spaces.

5.5 Analysis

5.5.1 Clarity in a space aids the creation of functional segments

In this experiment, when participants were exploring an environment made of a familiar space, being an apartment, they demonstrated the ability to break the space up into functional rooms. When participants were asked what helped them insert walls into their maps, most participants commented on objects being grouped together to create a cohesive space. For example, one participant wrote “*seeing the showers- where the sofa was and bed and wine cabinet made it easier to define what belonged where- like rooms but without walls*”, and similarly another participant wrote “*bedroom furniture indicates bedroom, bathroom furniture in bathroom, kitchen items (stove, washing machine in kitchen), TV & sofa in the living room/area*”. With these responses, it became clear that participants were developing a deeper understanding of the spaces within the environment, being able to conceptualise individual rooms within the overall environment. This conceptualisation is evident from the first participant claiming, “*like rooms but without walls*”, they were able to visualise the space already being subdivided before being prompted to do so. Similarly, participant two using the words “*bedroom*”, “*bathroom*”, and “*kitchen*” where none of these spaces were pre-defined or explicitly stated to the participants that the spaces would be made up of these rooms, their use of language highlights how they were interpreting the environments. It was not one big room with a lot of objects present in it, they were able to accurately subdivide the space and identify the function of each room.

Theoretically, this highlights an understanding of space not often considered in event segmentation research. Research into this topic places emphasis on the role of dividing boundaries and doorways on our ability to segment space (Radvansky, 2012); however, the necessity of doorways and boundaries to segment spaces does not appear to be as exclusive as some researchers claim. In the responses in this experiment, we see that the participants were already viewing individual spaces in the apartment as distinct rooms, as they were able to confidently name the rooms, despite the fact that there were no walls to separate these spaces. In this case, we would still expect to find the memory effects often attributed to event segmentation in this environment, despite no doorways being present. If that is the case, then perhaps the importance of local processing of space and existing schemas of how spaces are constructed should become a focus of event segmentation research.

5.5.2 Relying on physical constraints of objects in the environment.

While the previous theme highlighted participants' ability to subdivide space without the need for environmental boundaries, this ability appeared to be conditional on how familiar participants were with a space. When presented with an art gallery made up of multiple spaces, participants no longer were able to identify distinct rooms as consistently as when in the apartment environment. When asked what helped them break up their maps with walls, one participant stated, *"pictures and sink hanging in the air made the wall necessary to me to include where I did"*. While a second participant stated, *"One room had pictures hanging where i would expect walls to be, another "room" had sofas back-to-back and a book shelf, another room had tables and boxes against what i would expect to be a wall"*. With these responses, it is clear that participants were no longer grouping objects together to create distinct spaces but were more so relying on the physical limitations of objects, recognising that objects would not be floating in a space, and thus, a wall must be in this location. This theme of relying on physical constraints could signal a relatively shallower understanding of the space, where boundaries were not identified due to there being a room or subdivision in that space, but more so because a wall is needed there as the objects would not make physical sense without them.

This theme of relying on physical constraints is not only limited to objects floating or resting on walls, but also the size of objects. Some participants found that their wall judgements were more so based on where walls would or could fit, and less so thinking about what the purposes of the space are. One participant claimed, *"if a wall was there it would cut through the statue and the armchair"* while another stated *"A lot of statues that make the walls odd"*. Participants were less so thinking about how the contents of the rooms could be grouped together, or trying to make distinct spaces which could be identified in the environment. Conversely, participants were focusing on the physical restraints of the environment, namely a wall must go in a certain location as it cannot go elsewhere, or another location would not make physical sense. A lot of the literature around event segmentation emphasises the role of environmental boundaries and transitioning between them. Event boundaries are what divide environments into distinct spaces, and they are thought to be inherent and unambiguous, it is thought that event boundaries are clear and consistent. For example, when participants are asked to divide a video into distinct sequences, there is a large level of cohesion for where the boundaries are (Sasmita & Swallow, 2023). However, with these responses we see that while participants may place the walls in similar

locations across different environments, how they approach the task is quite different. Participants show a lack of awareness of the functionality of a room when there is ambiguity in the space, no longer thinking of the spaces in which objects can be grouped, or where walls would create distinct and knowable spaces, such as a kitchen or bedroom, instead thinking of the constraints of the space, namely objects cannot float without being attached to a wall, or a wall cannot bisect an object.

This raises some questions as to where we would expect to see the consequences of event segmentation on memory performance. Between these two approaches to inserting the walls, different thought processes are being used by participants, between creating rooms in the apartment, and inserting walls where they are needed in the art museum. With how participants approached these spaces, it would stand to reason that the consequences of event segmentation in these spaces would be different, too. The prominence of the segmentation may be related to the strength of the memory performance consequences, and so in more ambiguous spaces, such as the art museum, we would not observe the same memory performance abilities as we would see in the apartment environment.

5.5.3 Ambiguity impacts confidence for Segmenting Judgements

When participants were asked to identify if anything was out of place or odd in the environment, this response varied based on the familiarity of the space. When there was a lack of ambiguity, participants regularly answered that nothing seemed out of place, with some participants responding with “*no*” or “*nothing*”. With these responses, we can see that some participants were able to make sense of the entire environment, and were able to conceive of spaces where all objects fit in and made sense to them. These participants highlight two main ideas. One is that the environment they were in was compartmentalised enough that participants found it easy to incorporate all objects in the environments into cohesive rooms. These responses highlight how when there is cohesion and a strong sense of segmentation, some objects can be ignored or rationalised by the individual to belong in the spaces. Similarly, the participants were very confident in their wall placements that when they looked at the map they drew, they could not see any elements which may have been out of place or stood out as strange. The confidence in these judgements show that when there are strong segmentations made of distinct and clear spaces, some participants will focus on the elements that support the segmentations they made, being able to provide responses for what

helped them with their judgements, such as the theming of the room or grouping of objects together, but will be unable to provide any examples of objects appearing out of place.

However, some participants did identify a single object which they were unsure of. Examples of this include one participant answering, “*one of the basins*”, another responding “*What appeared to be a small tree in a pot in the lounge*”, and finally, a third responding with “*bookshelf near oven*”. The short nature of these responses may indicate how the participants were confident in their judgements and were clear on the spaces they delineated with walls. Only being able to draw out single objects when asked if anything was out of place in a large room with no walls or boundaries of any kind show the level of cohesiveness between participants. Participants were able to divide the spaces similarly, give the same labels to the spaces and to struggle to identify any objects which did not belong in their subdivisions.

Conversely, when the space was unfamiliar, participants expressed much greater levels of confusion. This confusion is highlighted by the large variance in responses, made up of long lists or whole areas of the environment seeming out of place. One participant responded that:

All the weird statue type things: the warrior with shield; the planet type thing; the giant chess piece with the serpent round it; the horse statue; the shape statue next to the horse. And also, the random sink opposite the shelves with boxes on. Two dining tables in one room and also two sofas back-to-back seemed strange. And the room with 2 tables and the armchairs seemed out of place.

This response exemplifies the uncertainty and confusion in the responses, the number of objects identified makes up a significant proportion of the objects present in the environment. These objects are significant not only in the proportion of the space they make up, but some of these objects, such as the statues, are large anchor points which some participants were using to make their wall judgements, and yet some participants were viewing these key elements of the space as out of place.

A lack of confidence in the wall judgements was also evident as some participants struggled conceptualising the space and could not make sense of how the objects in the space worked together. For example, one participant claimed “*I assumed there to be a wall where the red eyes painting was. But looking from the side, if a wall was there it would cut through the statue and the armchair. So, I imagined an angled wall.*”. This participant struggled to

conceptualise the space being subdivided with traditional walls and boundaries, and needed to produce a more creative way to break up the environment. When individual spaces were not as distinct, participants struggled to subdivide the space, highlighting that segmenting experiences is very dependent on cohesion and clarity, that when there is a lack of clarity, participants struggle to divide the space up confidently.

When participants are confident in their judgements, they were able to conceptualise and rationalise a space into their conceptualisation. Participants being unable to identify outliers in the apartment space shows the role of confidence in event segmentation, as when ambiguity is lower and participants make stronger segments, they are able to conceptualise of the whole environment, and the smaller spaces which make up that environment. Meanwhile, if ambiguity is higher, a lack of confidence hinders participants ability to conceptualise the space. While the spaces in the art gallery may have walls and room boundaries, participants' confidence in separating spaces would interfere with the impact of event segmentation on memory performance. As a result, research into event segmentation should be more conscious of these differences and take them into account when designing and reporting on an experiment.

5.5.4 Familiarity influences participants ability to conceptualise a space

When participants were asked to judge if anything was out of place for the apartment, some responses questioned the layout of the space. One participant focused on the lived-in experience of the apartment, stating that “Quantity of toilets and showers seemed out of place for someone who seem to live alone according to the size of the bed”. For the participant to be able to engage with the stimulus on this level, to imagine themselves living in this space and to question the choice of layout highlights how the participants developed a highly sophisticated conceptualisation of the space. Participants were asked if any objects seemed out of place, but for this participant to question the utility of the number of bathrooms in the space shows how comfortable participants were in their judgements, how clearly they could identify the spaces and to be able to go beyond individual objects making up a space, and consider higher functions like cohesion and utility. Similarly, another participant responded, *“The positioning of the oven, possibly the glass cabinet but that could be personal taste.”*. Participants in this environment were no longer trying to identify if individual objects were in the wrong location, but considering how they would change the space if they were in a

similar environment. To make judgements on the location of objects as a matter of taste, demonstrates how the participants were highly comfortable in their judgements and were no longer looking for anomalies in the space, but more so how to make the space more to their taste.

Alternatively, when asked the same question in regard to the art gallery, a lack of confidence in the wall judgements was evident as some participants struggled conceptualising the space and could not make sense of how the objects in the space worked together. This difficulty suggests that they could not visualise its purpose or utility, as they could with the apartment. When individual spaces were not as distinct, participants struggled to subdivide the space, highlighting that segmenting experiences is very dependent on cohesion and clarity; when there is a lack of clarity, participants became less able to divide the space up confidently.

However, this lack of clarity is not solely affecting participants' ability to divide the space, but also affecting participants' ability to identify the space that they are exploring. Despite this space being an art museum with a café attached, numerous participants still processed the space as an apartment or living space. For example, one participant referred to the rooms as "*livingroom*" and "*kitchen*", while another claimed, "*there were a lot of missing things, such as bathroom or bedroom*", and finally, a lot of participants called the space "*the apartment*". Despite the space not resembling an apartment, many participants still viewed it as one. This could be that exploring a living space is a more common experience than exploring an art gallery, and so participants tried to make the space fit into their preconceptions of an apartment.

Conceptualisation is a crucial part of event segmentation, as it is involved in the prediction used to generate segments (Kurby & Zacks, 2008). In the apartment space, responses suggest that objects which may challenge a function of a room and provide competition for the conceptualisation of a space are neglected by the participants. In order to segment the space, participants either forgot about outlying objects or rationalised them into belonging in those spaces, evident by some participants struggling to identify any out of place objects. When participants could identify outlying information, it would be a single object throughout the apartment, so even when they could identify an outlier, a majority of ambiguously placed stimuli were still neglected. It would appear from these responses that when segmentation of spaces is strong and highly conceptualised, there is a priority given to

the objects which support the judgements made by the individual, while objects contradicting these judgements are minimised or neglected.

Meanwhile participants being unable to identify the space they were exploring when in the art gallery has some implications for our understanding of event segmentation. These participants could place walls and divide the space, as they were using physics-based judgements, such as objects being unable to float, participants struggled to identify any distinct spaces based on the contents of the environment. It is thought that our ability to segment is inherent and consistent; however, these responses show that our ability to segment experiences may be more fallible and variable than initially believed. If there is familiarity about a space, participants could not identify the space they were exploring, and so, without distinct spaces and clear delineation, such as moving around an open space or an outside environment, our conceptualisation of individual events appears to be severely negatively impacted. This could also affect the consequences of event segmentation. If spaces are not clearly segmented or our conceptualisation of individual events has been impaired due to ambiguity, we would not expect to see the same memory effects as if exploring a clearly delineated space.

5.6 Discussion

The current experiment had two main aims. The first was whether memory and space segmentation was more accurate with high familiarity spaces in comparison to low familiarity spaces. The results of the experiment indicate that the familiarity of the space has a significant influence on participants ability to represent the space on a map drawing. While accuracy ratings for objects were similar across environments, accuracy ratings for walls were significantly better for high familiarity environments in comparison to low familiarity environments. The results indicate that for local objects and individual elements, there is not a strong influence of familiarity with the type of environment, and participants may utilise similar techniques in encoding and recalling objects in an open space. The findings suggest that any memory effects associated with event segmentation are more prominent when there is a visual/physical representation of an event boundary present in the environment. When event boundaries were not physically present in the environment, memory performance for objects was not different, regardless of familiarity with the environment.

However, when participants are in more familiar and highly compartmentalised environments, they have an easier time segmenting the environment into appropriate spaces, which can aid in memory performance and spatial learning. In comparison, low familiarity and more ambiguous spaces appear to be more difficult to segment appropriately, resulting in worse memory performance across almost all measures. These findings suggest that when participants are imposing/relying on their own generated segments, it is easier to segment a space when they are more familiar with an environment. With these established segments generated, they can affect how the participant perceives and engages with the environment, with participants becoming more confident and sure of their judgements, as demonstrated through the qualitative analysis.

The ratings for the map drawings were not the only measure throughout this experiment, and when we combine these findings with the findings of the qualitative analysis, a clearer image begins to emerge. The second aim of this experiment was to determine what factors were important in the process behind making segmentation judgements, and what are influential points in the environment which affect an individual's ability to segment. The first pattern that emerged in participants responses was that in highly familiar environments, participants appeared to be more confident in their judgements. They made clear and decisive choices of where walls would be placed on their maps and did not doubt or second guess these choices. A wall was placed to create a segmented space with meaning, such as a kitchen or bedroom. In comparison, when participants were asked about their choices in the low familiarity environment, there was a lot more uncertainty. Walls had to be placed in certain locations because they could not be placed elsewhere, such as a floating painting needs to be placed on a wall, and not because the walls were creating clear and distinct spaces.

A second pattern which emerged was the level in which participants were able to engage meaningfully with objects in the environments. In the highly familiar environment, participants were able to establish key features of a segment, such as a bed in the bedroom or shower in the bathroom, and establish connections between objects. These relationships between objects, their location and function helped participants establish distinct spaces, groups of objects could not be broken up, therefore they must exist in the same segment. This engagement with the objects was deep enough for some participants to comment on the layout of the space, what they liked in the space or what they found odd or different in comparison to their personal taste. On the other hand, in the low familiarity environment,

participants engaged with the objects in the space on a relatively shallower level. Some participants were unable to name the rooms they had created, despite their being a distinct painting gallery, statue gallery, café, and storeroom. If participants mentioned objects in the reasoning for their judgements in the low familiarity space, it was simply to say some objects needed to be on or against a wall, or a wall could not be in a certain location as it would result in a wall going through a statue or other object.

When we consider the results of the qualitative analysis, there is a significant difference in how participants engaged with the spaces. Participants being in a more familiar environment may result in better memory performance; additionally, it does have a significant impact on how they engage with the space they are learning. When participants are more secure in their segmenting, they can identify anchors in the environment, they can establish both spatial and semantic relationships between objects, and they are able to clearly identify and conceptualise the spaces they have created through their segments. All these factors resulted in significantly better memory performance. However, in low familiarity environments, participants had a shallower understanding of the space, often misidentifying the space as a whole, not considering the spaces they were creating, and mostly concerned with whether the walls they were drawing made physical sense in the space, not considering if it was needed or what function it would have served.

The significant differences in the map ratings represent how participants engaged with the spaces and how the factors identified by participants as being influential in their spatial judgements play a large role during segmentation. Our ability to segment is influenced by our familiarity with the space we are in.

5.6.1 Implications of findings

The current experiment explored which factors participants deemed to important and influential in learning of a space and segmenting ambiguous spaces. The difficulty of the spaces being learned or segmented is often not considered when researchers are designing experiments, and the results of this experiment suggest that is a large oversight in the research of event segmentation. The difficulty and familiarity of the spaces influenced what components in the environment were important in learning and segmenting, with low difficulty/high familiarity resulting in the grouping of the objects into meaningful groups, and

the relationship between objects establishing what spaces were being explored. Meanwhile, high difficulty/ low familiarity environments resulted in worse memory performance, meaning not being given to the objects and spaces, and segmentation based around physical constraints. These findings suggest that our ability to segment spaces is not as consistent as previously reported (Sasmita & Swallow, 2023), and that there are a number of potential influences impacting how we segment spaces. Previous research has considered the development of segmenting abilities, highlighting the differences in children's and adult's abilities to segment information (Zheng et al., 2020). The current findings suggest that there is more to learn about segmenting ability that may not be considered, such as environment complexity or familiarity. Not only could this give us insight into the variability of segmenting, but also the effects of segmenting may change depending on the environments being segmented.

As shown in the current experiment, the environments affected how participants engaged with the space and what information they considered important in segmentation, as well as influencing memory performance. If how we segment and perceive important components of the environment change, then we would expect that the effects of event segmentation would also change. The current findings support this, as memory performance was significantly more accurate in high familiarity environments in comparison to low familiarity environments. This change in effect is a novel finding, and there is more to uncover, such as what are the limits of these differences in perception and memory performance, what makes an environment particularly easy or difficult to segment, and so on. For event segmentation research and the EHM, the role of the spaces themselves, and the meaning of and relationship between the components of an environment need to be given more importance to account for how we engage with different types of spaces, as these findings suggest, there are large differences between how we perceive and engage with different environments which affect our ability to segment an environment and the effects of segmenting said environment.

Outside of event segmentation, this experiment highlights the importance of exploration in psychological research. Event segmentation has been an area of interest in psychology for the past two decades years, and yet a vast majority of the experiments exploring event segmentation follow the same paradigm. This paradigm was established by Radvansky through his "Walking through Doorways Causes Forgetting" series of studies

(Radvansky & Copeland, 2006; Radvansky et al., 2010; Radvansky et al., 2011; Pettijohn & Radvansky, 2016). It was through the inclusion of qualitative analysis and a novel experiment idea that findings of this experiment were found. These findings can be used as a starting point to explore many new facets of event segmentation research which would have not been considered under the previously established research paradigm. In order to push a field forward and to develop new perspectives on a phenomenon or problem, innovation is valuable, not only in theoretical ideas, but methodological practices as well.

This experiment utilised two unconventional approaches in its methodology which led to the current findings. The largest factor was the utilisation of mixed methods in the one experiment. Some researchers try to avoid crossing the divide between quantitative and qualitative research, which is potentially holding some research topics back. This can lead to issues such as areas often studied under quantitative approaches lacking rich data and individual insight on cognitive processes which may reveal underlying factors influencing cognition not currently being considered. On the other hand, areas often studied using qualitative methods may lack the statistical ability to operationalise and falsify some theories. In bridging these gaps in methodological approaches, as was done in the current experiment, research in numerous fields may uncover new findings leading to unexpected breakthroughs and exciting new areas of research.

The second methodological approach that led to the current findings were the mixture of multiple novel methods of carrying out the research. The largest of the novel apparatus was the VR setup. While VR does have its niche areas in psychology in which its range of uses is being applied, it is still a largely underutilised piece of equipment that can lead to unique ways of testing not possible in the real world (Wrzus et al., 2024). However, this is not to say VR is the only novel piece of equipment being underutilised. For example, Augmented Reality (AR) is another apparatus which could lead to interesting and previously unexplored areas of research being considered (Cipresso et al., 2018). While AR was not used in this experiment, the use of VR should encourage the consideration of different ways to test established theories and ideas. Similarly, while drawing is a widely utilised method of testing some phenomena in psychology, pairing it with the VR use has created a new research paradigm which yielded novel results. The current experiment highlighted the utility of using unconventional methods to bring a new perspective into an established research area. More researchers should be encouraged to adopt less conventional research approaches and a more

explorative perspective on some topics. Exploration and curiosity breeds innovation, and some areas of psychology are in need of innovation to push them further.

5.7 Conclusion

The current study aimed to explore what factors participants found to be influential in their segmenting decisions, and what effect does familiarity with a type of space influence these decisions. It was found that the components of an environment which were thought to be influential changed with familiarity, with high familiarity environments resulting in deeper engagement with the space, and segmentations made based on meaning and relationships between objects. On the other hand, low familiarity led to shallow engagement with the environment, resulting in segmenting based on physical constraints. These findings highlight how the difficulty in perceiving a scene can affect an individual's ability to effectively segment and learn an environment.

The findings of this experiment reveal a component to event segmentation which was currently not receiving attention, and it was through exploration and the utilisation of novel methodology that we highlight the role of the environment on participants ability to segment spaces. Moving forward, research can be carried out around perception of the environments, such as the extents to which difficulty influences memory and perception, and potential other influences of the environment on segmentation. Similarly, the findings of this study encourage the use of more unconventional methods in psychological research, such as the combination of quantitative and qualitative methods, and the utility of novel equipment such as VR, in order to gain a new perspective on research topics, and potentially uncover ideas that were not previously being considered.

Chapter 6 - General discussion

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6.1 History of event segmentation research

Event segmentation has been an area of interest in memory research for the past two decades, with earlier research focusing on reading tasks (Kurby & Zacks, 2008) and scene changes in movies (Cutting, 2014). Following this establishment of event segmentation research, researchers became interested in the role of event segmentation in spatial processing as demonstrated with the development of the EHM in 2012 by Radvansky. This model aimed to account for the complexities of everyday environments, where spaces have different layouts, functions, and sizes, and for how memory interacts with the process in breaking up everyday experiences. This model took account of the interconnectedness of information stored across different events, and the nuances in recalling separate events in different settings.

The publication of the EHM prompted a wave of research into the role of event segmentation in memory performance. One of the key findings of this new body of research claimed that doorways lead to forgetting (Lawrence & Peterson, 2016; Pettijohn & Radvansky, 2016; Wang et al., 2023). This reported phenomenon became a central focus of event segmentation research, particularly with Radvansky and Pettijohn carrying out several studies over the past 15 years under the series heading of “Walking through doorways causes forgetting” (Radvansky et al., 2015; Pettijohn & Radvansky, 2016, 2018). In this series of experiments, they looked at differences in age groups with the forgetting effects of event segmentation, environmental effects updating expectation disruptions, and so on. These experiments were carried out under the assumption that doorways cause forgetting, emphasising a small facet of the EHM, while ignoring the predicted beneficial effects that event segmentation can have on memory for scenes, as outlined in the EHM.

The assumption of the negative memory effects expanded beyond walking through doorways causing forgetting. Some researchers explored what factors about a boundary are important to induce the strongest memory effects, such as whether an event boundary functions or looks like a boundary is more important (Negen et al., 2020). Other researchers explored the role of expectation, asking participants to imagine walking through a doorway, and testing their memory performance (Lawrence & Peterson, 2016). While research was expanding on when forgetting effects occurred, there was still a focus on doorways causing

forgetting, and comparatively less research exploring other potential memory or cognitive effects of event segmentation.

It is only in the last few years that some research has pushed back against the idea that the most significant effect of event segmentation on spatial processing is a negative effect on memory performance. Some researchers explored the effects of event segmentation on the longevity of memory performance (Flores et al., 2017) and found both beneficial effects of segmenting effects one month later, but also that the aspects of the events remembered changed focus, going from fine grain to large grain detail orientation. On the other hand, some researchers have taken the research paradigm established by Radvansky, and applied them to different settings, such as outside (Peer & Epstein, 2021), expansive indoor environments (McFadyen et al., 2021), or giving the participants more control in movement and exploration (McFadyen et al., 2021). In these studies where real world conditions are better represented, the negative effect of event segmentation on memory performance is less consistent and a smaller effect.

Concerns about how the EHM was implemented into research, and the research test conditions contributed to the development of the current PhD project. A large proportion of the EHM is not accounted for in the studies which claim that doorways cause forgetting, as the model proposes conditions in which we would see beneficial effects of event segmentation. A second concern with this early research was the conditions under which event segmentation was being examined. These experiments often used empty rooms or spaces with very minimal design, and presented objects or words one at a time for participants to learn. While this approach could provide some insight into the effect of event segmentation on memory performance, it is not representative of the conditions under which we would segment events outside the lab. Event segmentation is a real-world process in which we break up an ongoing stream of information into meaningful units, and these experiments may not have meaningful or distinct spaces which would elicit a true segmenting response. It is also important to consider the generalisability of these studies and to ask whether these findings could be generalised to real world application.

There are also ambiguities in the EHM which have not currently been addressed through research such as how the core principles interact with each other, and what some of the terminology means under the context of event segmentation. An example of this ambiguity would be the role of “competition” within the model and its predictions.

Competition is not defined, so could be referring to similar appearing objects, objects in the same space, or object that have a meaningful relationship between them. Similarly, this project is motivated by the concerns of the methodology surrounding the EHM, and so ecological validity was a large consideration in the research design throughout this project. Efforts were made to ensure that participants could freely explore environments which they could potentially encounter in the real world, such as an office or an apartment, to ensure our findings were both representative of, and generalisable to, real world event segmentation and its related effects.

One important consideration for the generalisability and the application of the EHM is discussed by Aronowitz and Nadel (2023), who make an argument that space and not time provides the basic structure of memory. They argue that our encoding of time in memory is typically implicit action sequences that are precisely encoded and retrieved, and outside of specific events, we don't often recall information in time frames. As a result, the passage of time in a particular space does not affect our understanding of a space. On the other hand, spaces can act as a central and organisational feature of memory, where a number of events that occurred at different times can be linked together through space. This argument has strong implications for our understanding of event memory, and this argument should be considered when approaching the EHM.

6.2 Overview of Results

6.2.1 Do doorways cause forgetting?

An early goal of the project was to assess the claim that “doorways cause forgetting” under different conditions. We investigated how generalisable the forgetting effects of doorways were in real-world environments with different levels of complexity. As a result of these questions, we carried out similar memory tasks in more complex rooms that were explorable and with objects to learn. We found that when participants were presented with memory tasks associated with explorable, realistic scenes/rooms, there was no straightforward association (negative or positive) between doorways and memory ability.

Experiment 1 and 2 indicated that doorways in isolation do not lead to forgetting effects in memory performance. This is not to say that there is no effect. However, the lack of strong evidence for the idea that doorways cause forgetting validated our concerns about the research surrounding event segmentation. As there are a lot of claims as to how doorways lead to forgetting, the widely reported "doorways cause forgetting" effect may be a product of quite specific testing conditions.

The findings in these first two experiments raised concerns about the established research paradigm in event segmentation research. For one, it is not enough to test an idea in isolated settings for a theory which is orientated towards explaining memory and scene processing in real world environments. A pattern of findings not having generalisability or explanatory power for real world environments is a significant issue for a theory based around explaining how we traverse real such environments.

Secondly, our findings suggest that there could be other effects of event segmentation on memory that could be revealed when assessed in more realistic environments. The EHM suggests that there was potential for positive effects of event segmentation on memory; however, these potential beneficial effects were not being represented in research.

In the first two experiments in this project, there were mixed findings with regards to the memory effects of event segmentation. A number of factors were influential on our results, including whether participants were tested immediately after exploration or at a later stage, whether the information was provided as objects in an immersive environment or lists of words in an empty space, and whether the boundary was presented as a doorway or opaque divider.

The variability of these results suggests that while event boundaries do have a role to play in recall ability, this effect cannot be simplistically characterised, e.g., with 'doorways cause forgetting'. Environmental boundaries influence how an event is perceived and have a purpose within any given space which may lead to differences in the magnitude of their effect on memory. Moreover, not all event boundaries are processed equally; for example, a doorway and hallway would not elicit the same responses due to differences in spatial layout and the amount of time spent in the transition space between two meaningful events. Given that the results of the first two experiments highlighted how the effects of doorways on recall

were intertwined with other aspects of the environment, we were motivated to explore beyond the presence of the doorway in the next experiments.

6.2.2 When does the boundary matter?

We aimed to understand the characteristics of a doorway which would lead to differences in memory performance, and what environmental characteristics lead to doorway effects on memory performance becoming more prominent. Given that research surrounding factors which influencing boundaries is sparse, two main ideas were considered important to pursue with this project.

First, we sought to establish whether memory performance either improved or was hindered by a doorway bisecting two similar rooms, or two distinct rooms. With this research idea, we tested whether the presentation of the environments affected the function of the boundary, specifically assessing whether a doorway separating two similar rooms have a different influence on memory performance from a doorway separating two distinct rooms.

The second idea was what changes in the presentation of an environmental boundary. We sought to establish whether the boundary presentation would result in different memory performance from each other. We tested whether all boundaries were treated the same by participants, or whether different type of event boundaries (whether the boundary was presented as a doorway or corridor) yielded different memory effects.

The results of these Experiments 3 and 4 suggested that boundaries had an effect on memory (both positive and negative). This was not a memory effect unique to doorways, because all environments in these two experiments contained doorways, and there were significant differences in memory performance. A doorway in isolation was not sufficient to produce a reliable difference in memory performance. Perhaps unsurprisingly, across the two experiments boundary effects seemed to be strongest when attention was drawn to the segmentation or boundary. When rooms were distinct from each other, the boundary is emphasised as a dividing force due to its function of separating two incongruent spaces. This function is not as prominent when there are two similar spaces. Similarly, when participants were held within the boundary by traversing a corridor with doors that were opened by the researcher, the dividing nature of the boundary was made even more prominent, due to the

delay between traversing between two different spaces. Again, a function which is not as evident when one can simply walk through a doorway with no delay or effort.

From these two experiments, it appears as though emphasising the division between two spaces makes segmentation related differences in memory performance more prevalent. It follows that there is a need to be more explorative with event segmentation research. The exploration of different facets of the environment and boundaries allowed for a reframing of how memory was being influenced by environmental boundaries.

This finding encouraged a somewhat alternative approach to the next experiments. We did not solely focus on memory for objects in the spaces depending on how the space was being presented. Instead, we explored how navigation around a space and learning a spatial map may be influenced by event segmentation.

6.2.3 The role of event boundaries in spatial navigation and route learning

In Chapter 4, we explored what other forms of memory performance and scene processing may be affected by event segmentation. How we engage with environments and spaces is complex, and different facets of memory outside of recall for objects in a space are utilised to understand a scene. Some examples we were interested in exploring were spatial mapping of a scene, and route learning through a segmented space. We believed that expanding the research interest to include other forms of memory performance would aid in developing a more holistic understanding of event segmentation. Research surrounding the EHM and memory effects of event segmentation has been orientated around learning objects in a space and recalling them; however, this is not the only situation we would expect to see differences in memory performance. The areas of the brain associated with scene processing utilise an interconnected network to integrate both local objects and global elements to aid in navigation and route formation (Aminoff & Tarr, 2015; Baldassano et al., 2016; Dilks et al., 2013). With this interconnected neural network, it is likely that not only the processing of local objects is affected by event segmentation; we would also expect event segmentation to affect global features processing, thus impacting processes such as navigational ability and route formation.

In the experiments in Chapter 4, doorway effects interacted with the size of the disruption to expectation to influence identifying changes in routes, but were not the most

prominent influence on performance in identifying changes in an established route. What was more important in participants' ability to identify changes in a route was the size of disruption to expectations. Participants were asked to learn a sequence of images showing a route through an apartment, and identify when there were skips in the image sequence. Disruption to expectation was manipulated through the number of images skipped in an established sequence, with more images skips constituting larger disruption to expectations. In both experiment four and five, disruption to expectations were responsible for the main effects, wherein larger disruption to expectations led to superior abilities to identify skips, in terms of overall score, d prime, and criterion c. However, the prominence of doorways in the route had some influence on ability to identify skips, where doorways were a deciding factor for responses under uncertainty or ambiguous situations. Doorways facilitated the effects of disruption to expectations and difficulty of sequence, where when there were less images skipped, a high focus on doorways improved performance in the task. This interaction highlights how when attention is drawn to doorways, memory effects become more prominent but, in isolation, is not the most important factor.

The findings of Chapter 4 aided in clarifying the role of doorways in memory performance. However, there as an important component of event segmentation which was becoming an emerging concern. Throughout the experiments so far, boundaries and segments were imposed on the participants; however, how the participants were engaging with these segments remained somewhat unclear. There was a possibility that participants were subdividing spaces further than we envisaged in order to aid with memory and recall. On the other hand, the participants may not have been registering the spaces as two different segments and processing the space as one large space. The ambiguity created from not understanding the participants own segmenting behaviours raised a question not currently being addressed by event segmentation research. How do people segment spaces and what factors in a space are important in the generation of a segment?

6.2.4 Understanding what segmentation means to participants

A lot of research has been carried out to understand the effects of event segmentation on memory performance; however, comparatively little research has been carried out on understanding *how* we segment spaces and the development of segmentation abilities. Event segmentation research assumes that segmenting ability is consistent across participants and

any differences in performance is attributed to changes in the environment or the presence of a doorway. The final experimental chapter explored how we segment, and what factors in an environment are influential in segmenting a space.

A qualitative approach was adopted for this final experiment. Participants drew maps of the spaces they explored and gave open ended answers as to how they segmented their maps and their thoughts about the spaces they explored. The maps were rated by external raters, while the written responses were analysed through thematic analysis.

It became evident that how participants engage with the space is highly influenced by event segmentation. While there were significant differences in memory performance with the accuracy of the drawn maps, there were large discrepancies in participant responses to the environment. When environments were more familiar and more easily compartmentalised, participants displayed more confidence in their judgements as opposed to the less familiar spaces. As a result of these differences in how the spaces were approached, we could see that the levels in which the spaces were processed was being influenced, with participants in familiar spaces having a better understanding of the space they were exploring. These participants were able to correctly label the spaces and comment on the spatial layout. Conversely, in less familiar spaces more surface level processing was occurring where participants were focused on physical limitations of the space (walls could not bisect objects) and objects where walls were needed to logically exist in their current form (floating objects needed to be propped against a wall).

The results of this experiment have implications for our understanding of event segmentation, highlighting the variance in how we process segmenting information. This research should act as a springboard for further research into understanding how we segment spatial environments. The research paradigm established here could be used with children which could potentially develop a clearer understanding into how segmenting ability changes with age and how children understand segmented spaces. One finding which was clear from this experiment was that participants' ability to segment spaces was influenced by the spaces they were segmenting, and the influence of environmental differences should have a larger consideration in research moving forward.

6.3 Potential revisions to the event horizon model

This project identified a critical issue with one of the most influential models in the field being its use of terms which are not defined within the model. For example, “competition” is a core component of two of its five core principles, yet is not defined by the authors of the model. For the level of importance this concept holds within the EHM, this ambiguity in a core component reduces the model’s ability to explain and predict the effects of event segmentation on memory performance. One suggestion for the operationalisation of competition within this model would be to highlight different types of competition one might encounter when exploring an environment. The findings from Chapter 3 highlight the importance in competition on our understanding of event segmentation, both on an individual object level and a wider scene level, where differences in level of competition resulted in different memory performance. These findings support the suggestion that competition should be operationalised within this model. For example, to clarify competition, we could have:

- Inter-object competition - the conflict that arises when objects with a similar function are presented across event boundaries in multiple events. An example would be the presence of chairs in multiple adjoining scenes/events which may result in difficulties recalling which chair was present in which environment.
- Inter-environment competition – the conflict that arises when similar environments are presented side by side, rendering the differences between the environments as difficult to ascertain and reducing the prominence of the event boundary, thus reducing the effects of event segmentation on memory performance. An example would be two office spaces presented side by side, where it becomes difficult to recall in which adjoining space a particular object or feature belonged to.

While the clarification of some of the currently present components of the model would be invaluable for the predictive power and utility of the EHM, the model could also be improved through the inclusion of new principles. As evident through the results of Chapter 4, the inclusion of a section accounting for the environments being explored would serve to better account for variation in segmenting ability which currently is being underrepresented in the model, as is supported by the arguments made by Aronowitz and Nadel (2023) how

spaces organise event memory. This inclusion would explain that the effects of event segmentation are variable depending on a number of factors within the environment itself:

- Difficulty of the space being learned/traversed – higher difficulty spaces result in more difficulty in segmenting a space, and more reliance on the already established components of the environment. Lower difficulty can allow people to develop their own segments, as well as engage with the space on a deeper level. Difficulty changes the mindset which people approach a space and results in changed perceived abilities within that space. The differences both in memory performance and the participants perception of the task throughout Chapter 5 highlight how difficulty is an important consideration to be made.
- Prominence of segment boundaries/differences between spaces – when the presence of a boundary is highlighted for participants, such as segmenting aesthetically different spaces, or having a traversal space, such as a corridor, in comparison to a doorway, any event segmentation related differences in memory performance are emphasised. This was a commonly recurring theme throughout the project with the prominence of a boundary having an effect on memory performance, as shown with the heightened awareness of the boundary in experiment 3 both improving and hindering memory performance, the differences between doorways and corridors on memory performance in experiment 4, and the interaction with expectation throughout both experiments in chapter 4.
- Familiarity with types of spaces – where there is high familiarity with the spaces being explored, people can infer their own segments and judgements about the space, utilising their prior knowledge to make understanding a new space easier, and provide more confident judgements on a space. Low familiarity spaces reduce a participant's ability to make judgements about a space, having a lack of confidence in their own judgements. In these spaces there is less prior knowledge to draw on, and participants will be more reliant on the event boundaries imposed on them, resulting in more prominent effects of event segmentation on memory performance. Familiarity was seen to be an influence both in Chapter 5, but also is a potential influence on the results from experiment 3, where a lack of familiarity with a space station in comparison to an office could have had an important impact on findings.
- Frequency with which segments are traversed – people who often have to move between highly segmented spaces, or a large variance of spaces show a higher

threshold for what they recognise as an event boundary (Schwan & Garsoffky, 2008). For these people, they will be more resistant to the effects of event segmentation on memory performance. Comparatively, those who comparatively do not move through as many segmented spaces will be more sensitive to changes across events and will be more sensitive to the effects of event segmentation on memory performance.

As these inclusions focus on how prominent the memory effects of event segmentation would be for people exploring spaces, they can be considered a series of mediary effects which influence how strong differences in memory performance would be. However, there are two groups of mediary effects, the first being personal experience, which would be placed before any segmenting behaviour, to establish how sensitive an individual is to event segmentation. The second group are the environmental factors which establish how factors within the environment facilitate the effects of event segmentation on memory performance, and so would be placed at the end of the model. These mediary effects, in conjunction with clarifications in the current model, would significantly improve the predictive ability of the EHM, while highlighting that there is scope for the model to expand through future research, whether that is through the inclusion of mediary factors, or a component which considers the development of segmenting ability through different ages.

6.4 Purpose of the project

This explored issues with psychological research which are exemplified with work surrounding the EHM and event segmentation. Namely, the ecological validity of claims being made, and how generalisable the findings in research into event segmentation are to real life situations. Researchers were applying their findings of event segmentation on memory to complex environments; however, many experiments were carried out in scenarios not representative of real-world situations. While this research approach provided a good starting point for research, the paradigms utilised did not evolve to produce research representative of complex environments, continuing to utilise minimalist spaces. The EHM was developed to explain how we make sense of a continuous stream of information and how memory engages with complex environments (Radvansky, 2012), and yet research surrounding event segmentation was not representative of these complexities. As we showed throughout this project, the memory effects of event segmentation are dependent on

numerous environmental factors, impacting the prominence of the segments, which can affect how people engage with the environments.

A lot of the earlier research into the effects of event segmentation on memory performance made strong claims about the influence of doorways. Namely, there was a body of research claiming crossing through doorways were detrimental to memory performance (Pettijohn & Radvansky, 2016; Radvansky et al., 2015, Wang et al., 2023). This finding was concerned with how often we traverse through doorways and environmental boundaries. While crossing event boundaries does have an effect on memory performance, it is important to test these effects in context. Testing in the correct contexts allow researchers to determine the extent of these memory effects, how they interact with other aspects of memory and the environment. When these effects are tested in representative conditions, it allows us to establish how the results of these studies can be generalised to the real world. An effect or theory that can only be shown in isolation and is not observable in real world application is limited in its explanatory power or application.

Yet there is a large body of evidence supporting the claim of doorways cause forgetting due to the number of experiments carried out by and replicating the work of Radvansky and Pettijohn. With a large body of research such as this, the level of consistency we are seeing in the ‘doorways cause forgetting’ studies that we are seeing is of note. The number of studies which find detrimental effects of doorways on memory is unusual, without finding mixed results or beneficial effects. There is still more work to be done to reframe our perspective on research in psychology, and research surrounding the EHM and the effect of doorways on forgetting is an example of an area which a change in how we view and conduct research would be beneficial.

Another important purpose of this project is to bring attention to and to more deeply consider the philosophy of research. A common critique of event segmentation research throughout this project has been towards the repetition of the research being carried out, and how little these studies were advancing the EHM or our understanding of the memory effects of event segmentation. This project has shown the importance of considering *why* we are carrying out research, emphasising the importance of questioning currently established theories and pursuing the need to push our understanding of a concept further. These principles were explored in a number of ways throughout this project.

The first way was embracing non-significant results (Chapter 2 & 3), and using those findings to inspire the scope and subsequent directions of the project. Often in research, non-significant results are often minimised or glossed over in order to emphasise the significant findings. While there has been some shift in attitudes since replication became more of a concern within psychology from the replication crisis (Shrout & Rodgers, 2018), there still appears to be a bias, especially in publication, against reporting non-significant results (Van Aert et al., 2019). However, it is important for research and theories to be falsifiable, and accepting non-significant results is a part of that process (LeBel et al., 2017). Through embracing what areas were producing non-significant results, we could explore why these findings were not producing significant results, as we demonstrated through our approach to Chapter 3, as well as embracing more alternative perspectives on event segmentation and memory, as demonstrated through Chapter 4 and 5. Researchers should be more willing to pursue more interesting lines of inquiry, without fear of resulting in non-significant findings, as those findings are still valuable in identifying what factors are not important, as well as what factors are important. While more novel approaches to research do run a risk of not producing significant results, the knowledge gained from novel findings are invaluable and crucial to develop our knowledge and understanding of a given topic.

6.5 Real-world Implications

This project has many theoretical implications for approaches to research around event segmentation and theory, however, there is also a strong basis for real world implications as well. Namely, environmental psychology has a large role to play in architecture and interior design, and this project could support ideas and inform building designs. Montello (2007), discusses how physical environments can affect a number of psychological mechanisms and highlights sensory access, attention, behavioural affordance and memorability. For these mechanisms, “space syntax” provides an analytic approach to conceptualizing and quantitatively measuring the layout of built spaces, or places and how they are articulated into discrete, interconnected pieces. The ideas explored in this project provide an excellent addition to spatial design and architectural considerations, as understanding both how event boundaries affect the individual, and how individuals perceive event boundaries inform many of the ideas in this framework. For example, the differences between aesthetics or boundary layout as explored in Chapter 3 provide important

considerations for the interconnectedness and flow of a space, where the boundaries can act as punctuation within the space syntax. As discussed by Moser and Uzzell (2003), environmental psychology not only affects how an individual perceives and processes a space, but also their behaviour and actions with others and themselves within a given space. Environmental psychology can affect all levels of space, from private individual spaces, such as a home or dwelling, up to global environments, including both built and natural environments. Including some of the ideas identified in this project, such as confidence with familiarity or how boundaries can have a mediating effect on free recall and recognition, could be really valuable to environmental psychology and provide a strong basis for architectural design from a psychological perspective.

The role of doorways and walls was explored extensively throughout this project, and research supports how these architectural elements can affect the individual in a number of ways. Hamdy Mahmoud (2017), identifies the architectural considerations for the individual in terms of safety, privacy and functionality, and doorways and walls play a large role in all of these considerations. For safety, spaces should be adequate sizes with the right orientation and easy to understand layout, and event segmentation can help what makes a space easy to navigate and understand, with trying to reduce the number of event boundaries experienced on exit route to ensure the safety of the individuals within the building, and to make emergency evacuations effective and quick. With regards to privacy, public and private spaces should be clearly defined by means of applicable well-defined boundaries with differing degrees of interrelationship and connectivity with adjacent spaces. In this project, we explored what influences the prominence of environmental boundaries, and what draws out and minimises their effects. Understanding these factors can make spaces feel appropriate for function and ensure individuals are satisfied with the level of privacy in a space. Finally, in terms of functionality, it is important to adopt the concept of one space that can reflect different social functions. In this project, we highlighted how the perceived function and layout of a space can not only affect memory for a space, but also people's confidence in exploring a space. It is important for spaces to emphasise their functionality whilst still being attractive to the individual, and environmental boundaries have a large role to play here. Ensuring privacy, function and sociability can all be determined by the environmental boundaries of a space, whether open planned or a closed wall system and the complexity of the layout, and this project provides a thorough exploration of how environmental boundaries can affect perceptions of space and the individual.

Environments around us provide invaluable context and information that effects both how we engage with and perceive a space, and how we behave and feel within a space. When we are in a given space, we think about a space beyond just functionality and affordances within that space, but also how we exist in that space and more humane factors such as affect and emotion (Pagano et al., 2021). These are all important considerations for architects and designers, and this project provides useful insights which could inform design and architectural decisions in the future.

6.6 VR in psychological research

A core component of this project was the utilisation of VR as a methodology. As previously discussed, ecological validity and generalisability were a priority. From these concerns, VR became a viable solution to some of these concerns from a methodological perspective. VR allows researchers to easily develop the testing conditions they need to explore the concept they are interested in, with less concern for practical limitations. In essence, VR allows for the high level of control available in laboratory experiments, while having the generalisability and immersion of field experiments. The biggest constraint of using VR is the researcher themselves, as the creativity and capabilities of VR is limited to the researcher's imagination and developing capabilities (Rizzo et al., 2021; Wilson & Soranzo, 2015; Yaremych & Persky, 2019).

This project endorses the utilisation of VR in psychological research. For years, VR has been utilised in the field of psychology (Foreman, 2009), but often as an intervention method or a training tool. One example is in those with autism, where VR has been used effectively in social skills training, through creating safe environments for participants which can be catered to their needs (Frolli et al., 2012; Ke et al., 2022). Another example is in phobia treatments, where VR can provide a soft immersion therapy where, again, the stimulus can be tailored to the needs of the participant (Albakri et al., 2022; Freitas et al., 2021). While VR has demonstrated successes in therapeutic and intervention-based utility, its application to psychological research has been somewhat limited. This lack of utilisation of VR is an oversight on the psychological community's part due to the large scope of possibilities with using VR. From being able to address ethical issues from carrying out psychological experiments on the field (Ramirez, 2019), to the practical benefits of not needing a lot of equipment or different spaces while providing a realistic and immersive experience not achievable through a computer screen (Roberts et al., 2019).

However, one limitation to utilising VR in psychological research is the initial barrier to entry, requiring researchers to familiarise themselves with the skills and software to build environments, as well as the ability to code in a language not often used in psychology, such as C# or Python. Similarly, expense of equipment is often cited as a barrier to entry, with new equipment being perceived as costly. However, these limitations are not unique to VR, as any new form of testing has an initial barrier to entry and a learning curve which needs to be reconciled. While claims of difficulty or price are often reported with incorporating VR into research, it does not share the expenses of using more utilised equipment such as EEG, MRI, or TMS. Meanwhile, many psychologists engage in coding through the using R as a statistical analysis and graphing software, and so learning to code for other methodologies is not as large a barrier as some believe. While VR does have some issues with approachability, these are not limitations unique to VR, and thus, these limitations should be properly contextualised against the limitations of other methodologies and not significantly overestimated.

VR has the potential to allow for avenues of research previously not considered feasible or thought too impractical to create. This project demonstrated some of the ways to implement VR in research, showing how to begin to ask some of these questions and opening up a valuable space for experimental research. Every experiment that utilises VR in some capacity. Even in Chapter 4, where participants solely completed an online task, all the stimulus, videos, and environments used in the experiment were created and explored using VR. Beyond that, VR allowed for the creation of novel environments, such as a space station, floating objects in an apartment and art gallery, impossible elements such as a shimmer bisecting an environment, and so on. The use of novel environments allowed us to take concepts, such as contrasting and similar environments, and push it to the extremes, for example, creating a space station which is an experience participants would not have had, thus would have contrasted strongly with a mundane office environment. Floating objects allowed for us to alter an environment, where the remaining objects floating after removing walls created an ambiguous environment, which participants could interpret in different ways, allowing for the exploration of the thought processes behind segmenting spaces. Finally, utilising a shimmer allowed us to examine the nature of an event boundary, whether there was a memory effect unique to doorways, or if bisecting an environment through any means would result in differences in memory performance. VR was a core component of this project, and the project could not exist without it as a methodology. And while it was

instrumental, this project only scratches the surface of what experiments are possible with the utilisation of VR, and we aim to inspire more researchers to adopt this novel method of testing to create novel works which could be enlightening for the field of psychology.

6.7 Limitations

While this project provided good work in furthering our understanding of event segmentation in spatial memory and processing, there are some aspects which limit the project. The first limitation is the theoretical scope of the project, especially in earlier chapters. Due to previous research, there was a large focus on doorways on memory performance, and this created some restrictions on the project. Chapter 2 & 3 provided a thorough examination of the claim of doorways causing forgetting, and the results suggested that this claim is overexaggerated. However, being this thorough early in the project meant that the project could not focus on researching and proving theoretical ideas. We see with the later experimental chapters, such as 4 & 5, that the experiments became more exploratory, expanding on our knowledge and creating experimental paradigms which had not been utilised before. This was the correct direction for the project to progress in; however, the project remains open ended with a lot of avenues for follow up as a result of this approach. As noted previously, doorways are not a large focus of the EHM, and so, moving away from doorways earlier in the project would have benefitted the overall findings and conclusions of the project. It would have been stronger to have developed this exploratory approach earlier in the project, that way we could have concluded the project with an experiment which tested and proved a specific theoretical idea. While the project examines event segmentation and memory performance, there is potential to focus the scope of this project to produce clear and definitive theoretical ideas.

While the theoretical scope of this project highlights a limitation for applicability due to an open ended ending to the project, the methodological approach could also be viewed as a limitation. This project utilises under utilised methods to show novel results and this is one of the strengths of this project. However, there are practical limitations with this approach which may have hindered data collection. The largest of which is the focus on Virtual Reality. While I am a proponent of VR in psychological research, I acknowledge that it is time consuming and participants need to be tested one at a time. If I was to adopt more traditional methods in more of the experiments, we would have more data to work with,

which would be able to provide more insights into the discussed processes. Many experiments within this project could have benefitted from having a higher number of participants, however, this was not possible with the methods we were using. If some of the experiments would have used computer tasks which could have been completed at home, or on multiple computers at once, number of participants would not have been as much of a concern as it became throughout this project.

On the other hand, a lot of memory research considers neuroscience perspectives, and as a result, combine behavioural and neuroscience methods. For example, there is a body of work discussing the OPA, PPA, and RSC with regards to boundaries and special processing. It would have been a great addition to this project to be able to explore ideas around event segmentation specifically while targeting these brain areas. While this was originally planned for this project, unfortunately it was unable to be carried out. And so, being able to incorporate some brain image methods would have been very valuable to this project, as there is a neural basis for this work, and being able to incorporate that aspect would have provided a more holistic perspective on the topic.

While these limitations exist within this project, they also provide exciting potential for follow-ups to the work carried out here, and there are many things to learn, both theoretically and methodologically, from this project. Research can continue to develop on the more exploratory and unconventional approaches utilised throughout this project to reveal some interesting insights into our understanding of event segmentation and memory.

6.8 Conclusion

The aims of this project have been numerous, ranging from addressing issues in existing theoretical accounts in event segmentation research to highlighting issues with approaches to research in wider psychology. This project suggests a reframing of how we approach event boundaries effects on memory in research. To suggest that there is a single memory effect from a component of the environment is reductive and belies the complexities of both memory processes and the environments we traverse. Through a series of experiments, this project demonstrated how variable the memory effects of event segmentation can be. Crossing event boundaries can result in both improvements and impairments to memory performance. The studies also highlight the role of doorways and event boundaries in the context of environments. To isolate the role of event boundaries on

memory performance, and to not consider the context of the events those boundaries are segmenting is not productive to develop our understanding of memory effects of event segmentation. Through exploration, this project has identified the role of attention being drawn to event boundaries, and the interaction between event boundaries and other factors in the environment.

Not only has this project aimed to clarify the role of event boundaries in memory performance, but to expand our understanding of memory performance and segmenting events. This project looked at other ways in which memory is used in spatial processing and scene perception, for example, route learning and developing a spatial map. These aspects of memory performance have often been neglected in event segmentation research, however, given their prominence in spatial processing, this series of experiments drew attention to expanding the scope of the memory effects of event segmentation.

Another neglected area in event segmentation research is understanding how we segment spaces and what impacts our ability to segment a space. By analysing participants conscious thought processes behind segmenting tasks, it became evident that there is a large variability in our ability to segment spaces dependent on the spaces we are exploring. Considerations for the influence on our ability to segment a space have not been explored in research; however, the findings of this project suggest that it is a key component in understanding the interaction between event segmentation and memory performance. A suggestion for future research would be to focus on tasks where participants would need to segment a space, to observe what patterns emerge when participants are imposing their own segments, and look at whether there are memory effects from these self-imposed segments. Another potential idea for future research would be a rating tasks, where participants are asked to order or rank the importance of environmental components in segmenting judgements, thus operationalising the concepts discussed through the qualitative questions from Chapter 5.

Based on the findings of these experiments, a number of revisions have been suggested for the prominent theoretical model in this literature, the EHM. We suggest there is a need to more directly consider the abilities of the individual, the presentation of the space being explored, and to clarify some of the terminology currently present in the model which created ambiguity, namely the term “competition”. With these revisions, the predictive power of the model is improved, ambiguities are clarified, and the model develops a more holistic

approach to spatial processing which is representative of the complexities of real world environments and the variability of human abilities.

Some of the wider aims of this project were to emphasise the importance of ecological validity and generalisability of research findings. While testing in more realistic conditions did not support the idea of doorways causing forgetting, there were a number of findings which were found which were being neglected under the more reductive practices of previous research paradigms. Some examples are the importance of the prominence of the event boundary, and the role of difficulty and familiarity in segmenting ability. A general suggestion to incorporate this consideration of ecological validity would be to replicate lab experiments which produced statistically significant results, and reproduce them in more ecologically valid scenarios. This could be through the use of VR as this project demonstrated, carrying out research in the field, or changing the methodology from a computer task to a more interactive task. Within the topic of event segmentation, this project provided a template for how to maintain ecological validity as a core consideration in research design, and moving forward, it is important for event segmentation research to utilise complex environments which we may encounter in the real world, or alternatively, use real world environments to increase ecological validity and generalisability. The task is also important in this discussion, where implementing different types of tasks, such as route learning or map drawing, to be conscious of the complexities of memory and explore the memory effects of event segmentation more thoroughly.

A number of non-significant results were found, and the role of non-significant results as a part of the research process was highlighted throughout this project. Often null results are not reported or minimised in favour of significant results, and this attitude towards null results has led to a bias in publication of research. However, null results play an important role in research, as they identify avenues of thought which may not be worth pursuing, and can also inspire more novel lines of research to try to explain the presence of null results. Research should be falsifiable, and a part of that is accepting when non-significant results are found. Non-significant results were found early in this project, which lead to the development of more novel methods of examining event segmentation, which revealed and highlighted areas which were not currently being considered in research, such as the development and variability of segmenting ability. Research should be carried out with the intention of expanding our knowledge and understanding, and attitudes towards null results are restricting

that advancement. This project exemplifies when researchers embrace null results and falsification, more significant jumps in our understanding of a concept can be made. Future suggestions for research practices would be to encourage the pre-registration of studies, as sharing research plans before conducting them would increase transparency into the methods and analysis being utilised. Another suggestion would be to encourage more open science practices, such as open access, which removes the financial barrier to research papers, allowing for the wider dissemination of knowledge and makes research information more readily available. Another example of open practices is open data, where the datasets used is available for other researchers, which encourages replication and utilisation in meta-analysis. Having research data and papers more readily available encourages researchers to be more collaborative and to learn more from the data and methods, and to be less so focused on publishing significant results, which would be less receptive of non-significant results due to a publication bias.

Finally, this project embraces innovative methods of testing, namely VR and the use of qualitative methods in a traditionally quantitative field, and encourages researchers to adopt a similar attitude towards research. Embracing lesser used methodologies can be fruitful in expanding our understanding of a topic, potentially revealing lines of thought which were not being considered by wider research. To not conform to established research paradigms, and to create your own methods of testing can be invaluable to a topic of research (Giles, 2013). A novel method and finding, while carrying risks of not being embraced by the field or not producing the expected results, is more valuable to our understanding of a topic, than a group of experiments which do not try to push the boundaries of our understanding.

In essence, this project advocates breaking moulds and pushing the boundaries of research attitudes and practices. Established theories can and should be challenged, regardless of the body of evidence supporting it, if there are oversights not being addressed, or concerns that can be minimised with the use of bespoke methods. This project demonstrates how challenging a model can result in revisions to strengthen its predictive and explanatory power, to use novel methodologies and practices to generate new and exciting experiments which can bear novel findings, both in supporting previously established ideas, and uncovering new results which are not being highlighted by current research. Through using innovative methods, we considered and explored how we segment ambiguous spaces, where the findings highlighted the influence of space on segmenting ability.

This project embraces creativity and exploration, carrying out research that interests the researcher and carrying out research in a pursuit of knowledge and interest, regardless of the risk of non-significant results or criticism from other researchers in the same field. We took a more creative approach to studying event segmentation, exploring the concepts of spaces and boundaries and what they mean for segmentation influencing recall ability. We were also able to study other forms of memory performance for a scene in route learning and map drawing. Through expanding how we tested event segmentation, we learned more about how event boundaries interact with other aspects of a scene to influence memory performance, as well as other factors, such as size of disruption to expectations, which influence memory performance more. This project should encourage other researchers to do the same, to embrace exploration and the pursuit of knowledge, and to truly consider the reasoning behind carrying out research.

And finally, this project disputes the repeated claim that doorways cause forgetting. From the first experiment of this project, the influence of doorways was demonstrated to be more complex than a simple cause and effect. Doorways and environmental boundaries have a complex relationship with the structuring of memory, utilising previous knowledge, established schemas, and incorporating other processes such as prediction error and navigational abilities. This is a topic that benefits from exploration, as memory in complex environments is a complex process, and should be treated as such. Doorways and environmental boundaries can inform memory, structure memory, aid in its organisation and provide valuable information. However, they can also disrupt the flow of information, add to cognitive load, and can have a detrimental impact on recall and recognition, depending on the environments and the tasks being asked of the individual. However, to claim doorways cause forgetting is not an accurate representation of event segmentation in memory.

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Appendices

Appendix A

Images of the environments

Experiment 1

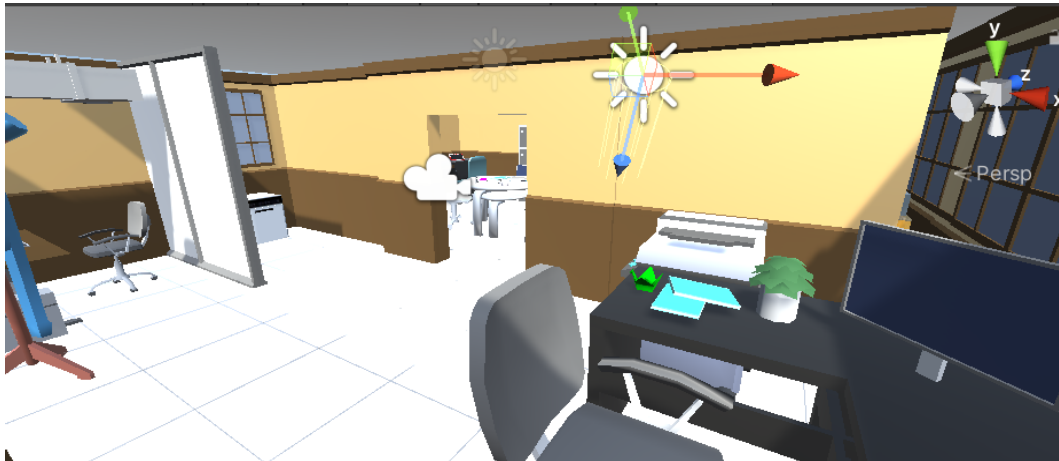
Shimmer



No Boundary

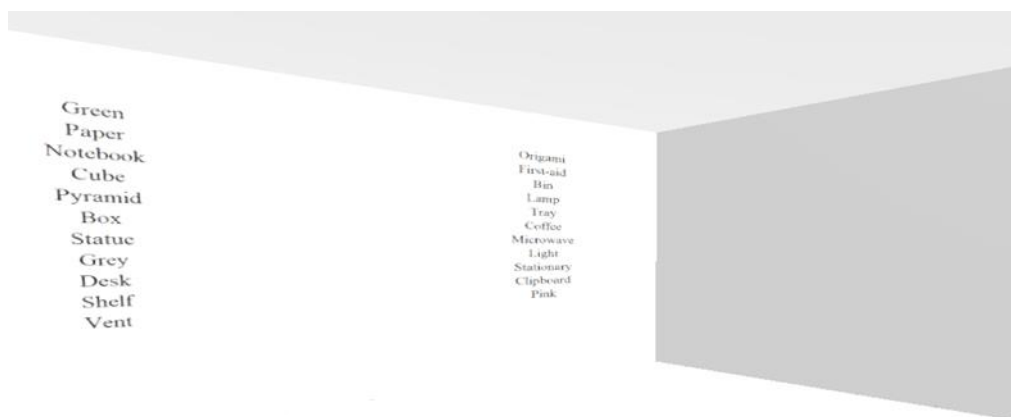


Doorway

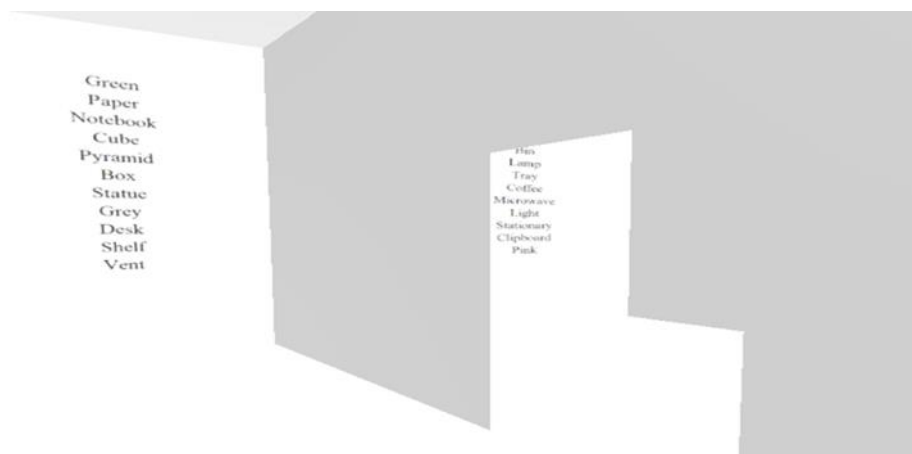


Experiment 2

No Boundary

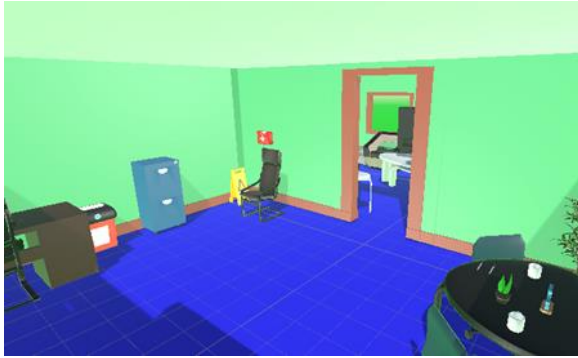


Doorway

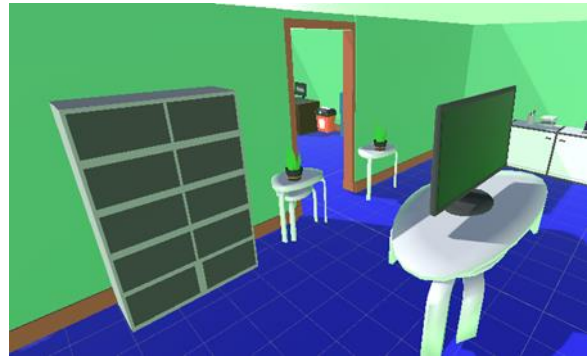


Experiment 3

Similar Environments

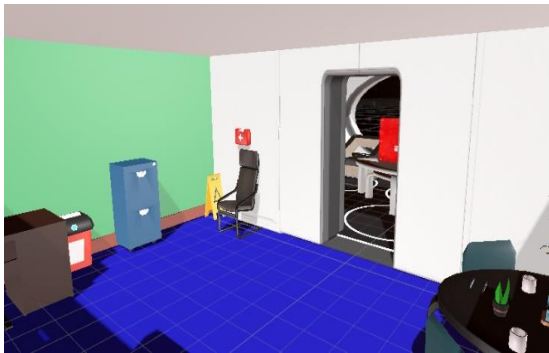


Starting Room

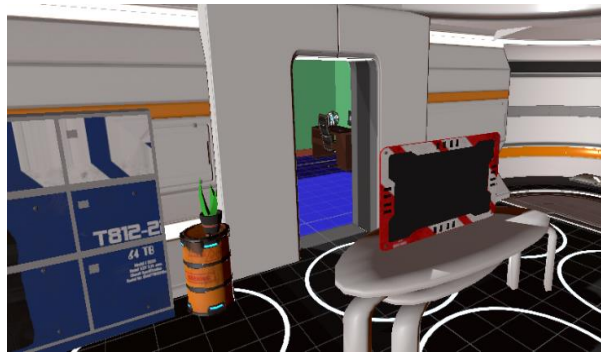


Adjoining Room

Different Environments



Starting Room



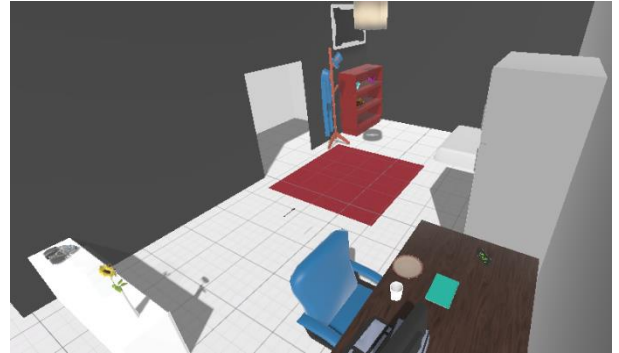
Adjoining Room

Experiment 4

Apartment



Starting Room



Adjoining Room

Birds Eye View



Doorway Condition

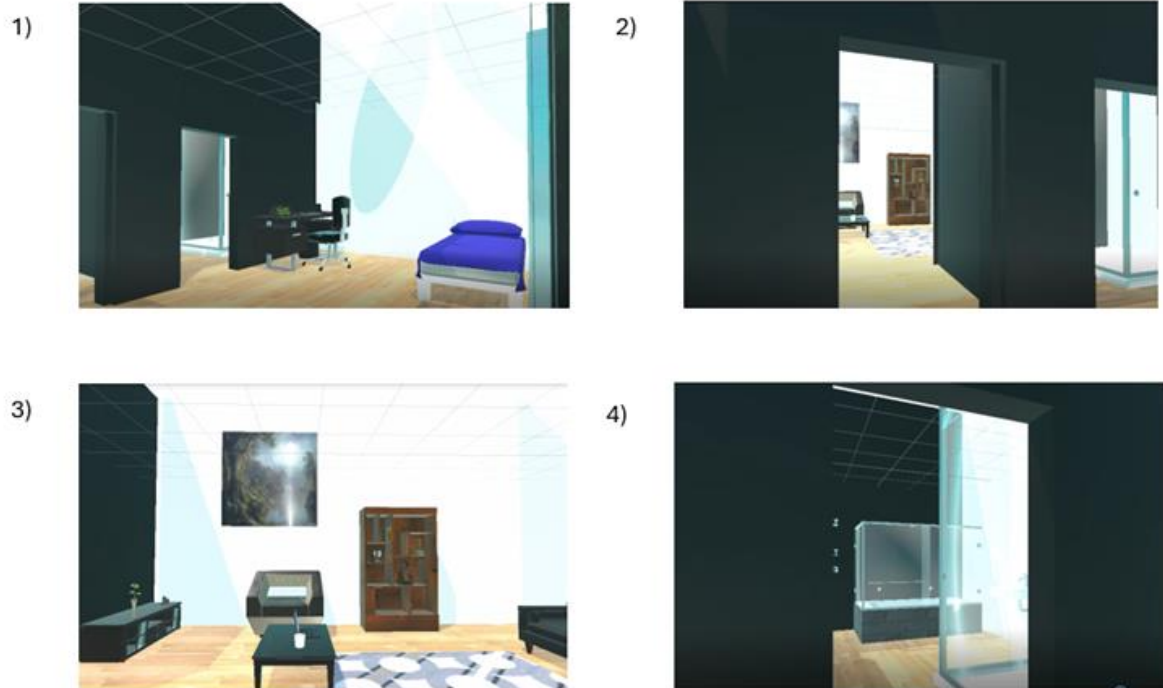


Corridor Condition

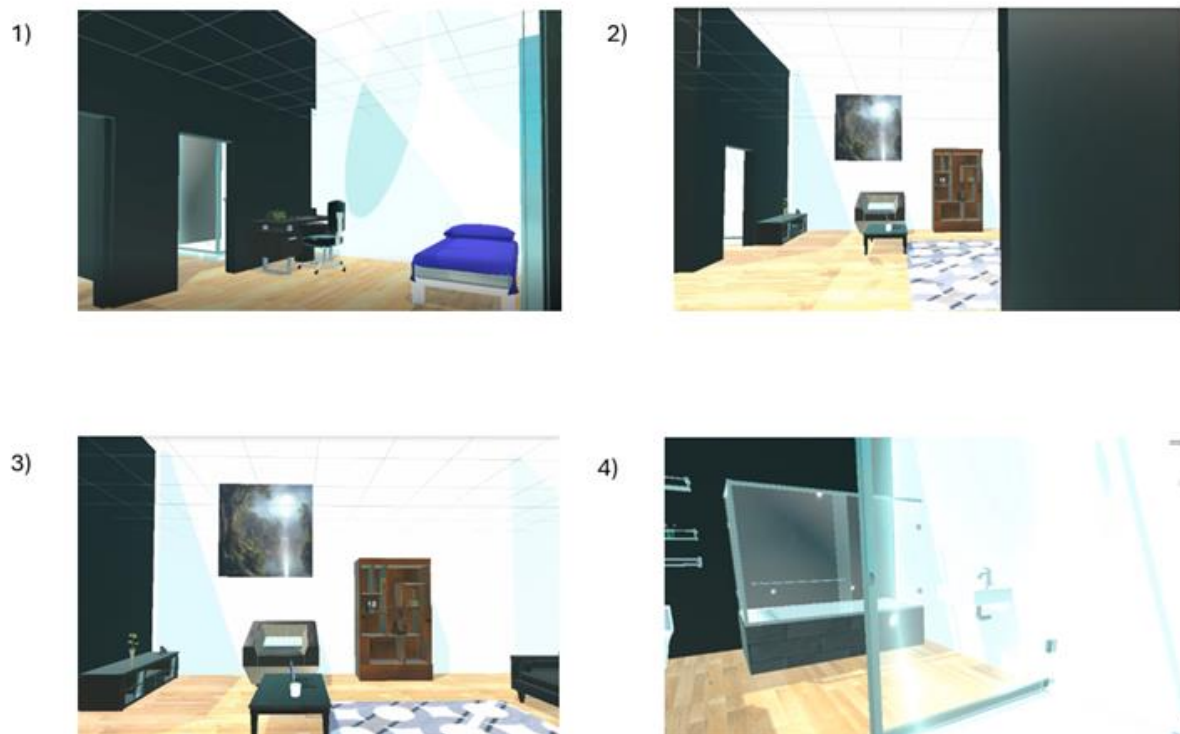
Experiment 5 & 6

Apartment

High Event Segmentation Focus



Low Segmentation Focus



Experiment 7

Apartment Birds Eye view

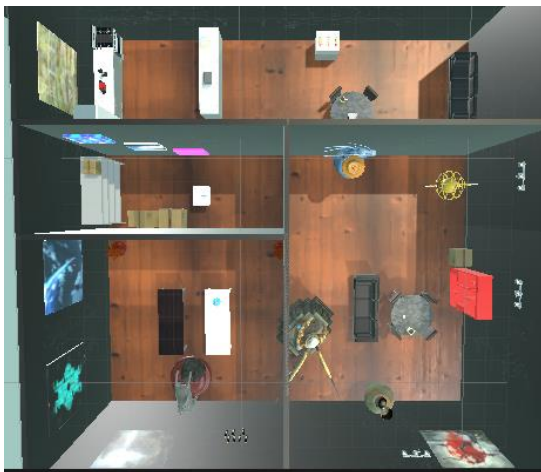


With Walls

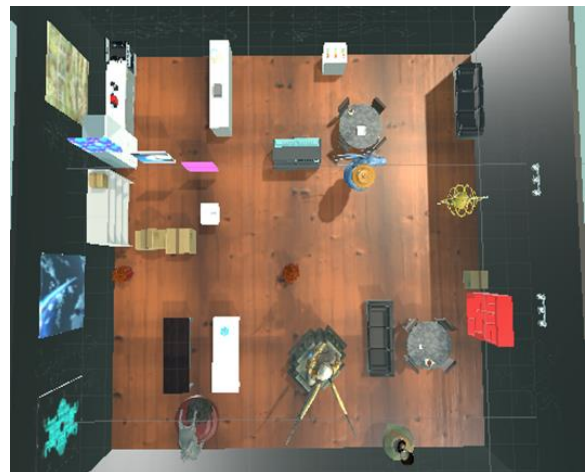


Without Walls

Art Gallery Birds Eye View



With Walls



Without Walls

Appendix B

Experiment 1 – 4 Tasks

Free Recall

Please write below all the objects you can remember seeing in the environment (if there were multiple of the same objects, only list multiple times if there was a distinct difference between them. For example, red book, green book etc. You do not need to count each individual time you saw an object)

Next

Example Forced Choice Recognition Question

Choose the correct image

A)



B)



C)



- ☐ A
- ☐ B
- ☐ C

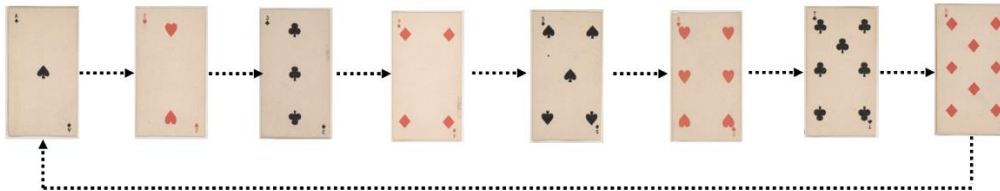
Next

Appendix C

Experiment 5 & 6 Instructions

In this experiment you will see a series of images – one at a time – in a sequence.

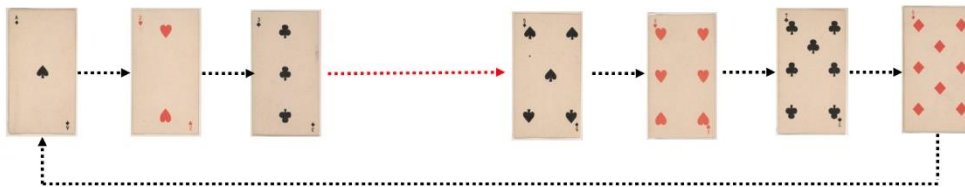
For example, see the sequence of cards below going from Ace of Spades to the 8 of Diamonds, and then looping back again.



You will see the image sequences repeatedly and look for when there is a change to the sequence.

As soon as you notice a change, press the *spacebar* as fast as possible.

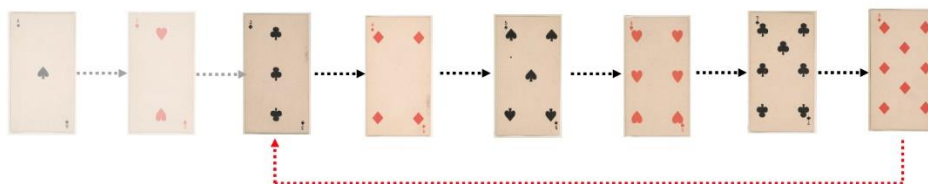
For example, see the sequence of cards below.



The sequence goes suddenly goes from the 3 of Clubs to the 5 of Spades, skipping the 4 of Diamonds. When you see that 5 of Spades should not have been the next image, press the spacebar as quickly as possible.

In this case, the sequence went from the 8 of Diamonds, to the 3 of Clubs skipping the first two cards in the sequence.

Here again, you would press the spacebar as soon as you noticed a change in the sequence.



If you correctly respond to a change in the sequence, you will see **CORRECT** on the screen.

If you respond when there is no change, you will see **INCORRECT** on the screen.

If there is a change, but you don't respond, you will see **MISS** on the screen.



Remember, the task is to respond as quickly and as accurately as possible.

Let's try an example.

You will first see the sequence loop through once to get you used to the experiment.

After that, you will see changes begin to appear in the loops. Press the spacebar as soon as you see these.

Press the spacebar to start.

Thank You! We will now move on to the main experiment.



However, instead of cards, the experiment will use pictures of scenes.



These picture were taken by someone walking in a loop.

As before, your task is to look for changes to the sequence.
You will again see the sequence 2 times in full before the
changes start to appear.



Please keep your hand on the spacebar throughout
and respond as fast and accurately as possible.



Press spacebar to start

We will first show you a short point-of view
video of someone walking in a circuit.

Press the button to see the video.

Appendix D

Experiment 7 Tasks

Reasons for Judgements questions

What objects were important in making your wall/ naming judgements?

Did any objects seem out of place?

Next 

Rating Scales

How accurately are the size of the objects represented



How accurately are the location of the objects represented



How accurately are the location of the walls represented



Are the correct number drawn of...

Some missing -3 -2 -1 0 1 2 Some extra 3

Objects



Walls



Appendix E

UEA Virtual Reality Lab Protocols

Document Title: VR/VA Lab Access Protocol

Author: Malcolm Rae

Review Date: 16/09/2019

SCHOOL OF PSYCHOLOGY – VR LAB ACCESS PROTOCOL

Before being granted access to the VR Lab space, users will need to complete the following steps:

- 1) Read all safety and lab procedure information in this document.
- 2) Complete VR Lab equipment training session and safety briefing with PSY Technical staff.
- 3) Receive emailed approval from VR Lab Lead (TBC).

Continued access to all labs is contingent on adherence to the usage instructions contained in this document as well as ensuring that lab spaces are always returned to the initial state after each use as described in the 'Post Use' section of this document. These procedures are in place to ensure that lab equipment remains in an undamaged and fully operational state, as well as minimising any risk to operators and trial participants arising from use of the space by untrained users. Study design recommendations where given, are not exhaustive and further advice can be provided by the lab lead, or technical team as appropriate.

VR OVERVIEW

The use of Immersive, and semi-immersive Virtual Reality equipment is relatively risk free, however there are some potential side effects from use of this equipment. The most common risk associated with use of VR equipment is related to a physiological response to the presentation of visual information in a manner that differs from the natural world, and associated risks and mitigation are discussed in this document.

RISKS

Physical

- **Headsets:**
 - Headsets are relatively heavy, (NVISOR units in VR lab are > 1Kg) and can potentially cause user discomfort if worn for extended periods of time (>20 Minutes). The additional inertia arising from headsets should be borne in mind when designing trials and the need for rapid or repeated head movements should be minimised as far as possible. Effects from prolonged use may be partially mitigated by avoidance of extended periods of inactivity and ensuring correct fit of headset.
 - Thought should be given to the existing visual acuity of participants as this factor is not only significant in affecting the incidence of simulator sickness, but also,

any constraints arising from the fitting of the HMD that preclude the wearing of normal prescription glasses are likely to heighten the risk of a negative response in participants.

- **Impact:** Whilst wearing Head Mounted Display in a fully immersive VR scenario, the participant will be unable to see their surrounding environment. As such they will be susceptible to trip or impact hazards and should be closely monitored for the entirety of the task to ensure their safety.
- **Visual:** Trials into 'simulator sickness' suggest that anywhere between 30% - 60% of participants using fully immersive VR systems may experience some form of negative response following a 20 minute sustained use, including; nausea, headaches, disorientation and transient changes to levels of visual acuity
- **Hygiene:** Head Mounted Displays need to be close fitting, particularly around the facial area where the display will likely be in direct contact with the face. This will typically lead to higher than normal levels of perspiration exacerbated by the fact that HMD displays often generate significant heat. This presents a risk of transmission of pathogens, and HMDs should be cleaned thoroughly before and after use.

ADDITIONAL CONSIDERATIONS

- In a VR environment, computer generated images are displayed on two-dimensional screens requiring the eye to remain focussed at a fixed distance. The presentation of three-dimensional binocular images on that screen however, forces the eye to change direction as though looking at objects at both distant, and close ranges. The mismatch between the focussing, and eye alignment systems can cause pressure on the human visual system as it attempts to adapt. This can lead to a number of symptoms, collectively referred to as 'Simulator Sickness'. Where possible, trial environments should be designed to minimise the need to repeatedly vary focal distance in order to reduce the incidence of simulator sickness.
- Simulator sickness can also be caused by a mismatch between the sensory systems and the inner ear, where the visual system is presenting movement through a space, which is not matched or detected by the inner-ear. Where possible, VR scenarios should be designed to minimise instances that highlight this mismatch.
- Whilst Virtual Reality is not currently good enough to be confused with actual reality, it is sufficiently realistic to trick the subconscious brain into thinking that the user is really in a given situation. Because of this, wearing a fully immersive HMD can trigger phobias such as a fear of heights. While this can be used therapeutically to help patients deal with those phobias in a safe and controlled way, it can also cause a severe shock to a user who is not expecting to confront their fear.

- Reduced capacity to concentrate on visual tasks is symptomatic of simulator sickness and will likely impact reliability of results from trials where this is a target measure.
- Symptoms of virtual reality exposure can persist and become more apparent hours after use. These post-use symptoms can include all the typical symptoms of simulator sickness, as well as excessive drowsiness and decreased ability to multi-task. These symptoms may put participants at an increased risk of injury when engaging in normal activities in the real world and participants should be appraised of potential symptoms. Additionally for studies where individual participants will be attending on multiple occasions, the post-use questionnaire should be used to help identify those susceptible to simulator sickness.

CONTRAINDICATIONS

- Simulator sickness is more likely to affect children between the ages of 2-13 years so it is recommended that participants are not used from this age range.
- History of photosensitive epilepsy
- Pre-Existing binocular vision abnormalities
- History of motion sickness/nausea
- Participants should complete the pre, and post exposure Simulator [Questionnaire](#) (Kennedy et al, 1993)

TRAINING

Training, and equipment usage advice will be provided by the PSY Technical team, and will include:

- Correct fitment of HMD
- Cleaning of HMD
- Design of trial to minimise simulator sickness
- Trip hazard avoidance
- Use of Motion Capture software/Hardware
- Correct use of HMD to minimise damage
- Study risk assessment

LAB RESPONSIBILITIES

Authorisation of users: VR Lab Lead

Maintenance of VR equipment: PSY Technical Team

Lab door access control: PSY Technical Support

Design of studies: Lab Users

Technical assistance: Lab lead and/or PSY technical support

Setup of equipment, and post use cleaning, and return of lab to original state: Lab users

Lab consumables: PSY Technical support

POST USE PROCEDURES

- Ensure VR HMDs are switched off on device (Power indicator turns red)
- Power down VR PC
- Power down Qualisys Motion tracking PC and associated Network devices, see [HERE](#) for instructions

EMERGENCY PROCEDURES

In the event of a medical incident in the VR Lab, the School First Aiders are:

Richard Carey-Knight LSB Rm 01.07 Extn 3975 Mobile #####

In the event of a technical issue, the technical team are located in LSB 01.07 and can be contacted on Extn 3975 or 3385

SIMULATOR SICKNESS QUESTIONNAIRE

No_____ Date_____ Pre/Post_____

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort

None Slight Moderate Severe

2. Fatigue

None Slight Moderate Severe

3. Headache

None Slight Moderate Severe

4. Eye strain

None Slight Moderate Severe

5. Difficulty focusing

None Slight Moderate Severe

6. Salivation increasing

None Slight Moderate Severe

7. Sweating

None	Slight	Moderate	Severe
------	--------	----------	--------

8. Nausea

None	Slight	Moderate	Severe
------	--------	----------	--------

9. Difficulty concentrating

None	Slight	Moderate	Severe
------	--------	----------	--------

10. « Fullness of the Head »

None	Slight	Moderate	Severe
------	--------	----------	--------

11. Blurred vision

None	Slight	Moderate	Severe
------	--------	----------	--------

12. Dizziness with eyes open

None	Slight	Moderate	Severe
------	--------	----------	--------

13. Dizziness with eyes closed

None	Slight	Moderate	Severe
------	--------	----------	--------

14. *Vertigo

None	Slight	Moderate	Severe
------	--------	----------	--------

15. **Stomach awareness

None	Slight	Moderate	Severe
------	--------	----------	--------

16. Burping

None

Slight

Moderate

Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Appendix F

Examples of Written Responses for Qualitative Analysis

What objects were important in making your wall/ naming judgements? (Apartment)

1. seeing the showers- where the sofa was and bed and wine cabinet made it easier to define what belonged where- like rooms but without walls.
2. Functional objects like bath, washing machine, desk, bed.
3. bedroom furniture indicates bedroom, bathroom furniture in bathroom, kitchen items (stove, washing machine in kitchen), TV & sofa in the living room/area
4. "I noticed common place everyday objects which would usually denote the purpose of a specific room/area. For example: The location of bed, suggested the area would be used for sleeping, ie a bedroom. The location of a sink and toilet off the bedroom, suggested the area was used as an ensuite. The location of a sofa, suggested the area would be used as a living room.

Did any objects seem out of place? (Apartment)

1. no? just the room placements seemed odd, bathroom right next to the front door?
2. the Oven and the central toilet until I drew the walls
3. The positioning of the oven, possibly the glass cabinet but that could be personal taste.
4. No

What objects were important in making your wall/ naming judgements? (Art Gallery)

1. One room had pictures hanging where I would expect walls to be, another "room" had sofas back to back and a book shelf, another room had tables and boxes against what I would expect to be a wall
2. The pictures can't hang in mid air. the storage in the kitchen needs to be in an enclosed area as not nice for customers to look at. the sink needed a wall to hang from and for customers health and hygiene. on reflection the sink needed something to rest on it was in mid air.
3. Looking for key indicators to tell me what each room was as certain things just wouldn't belong together like the fridge and sofa wouldn't be together- so key things were chairs/tables for living, oven/fridge for kitchen, tables/alcohol for dining room.
4. Paintings/ floating appliances (ie sink). Used couches as reference point

Did any objects seem out of place? (Art Gallery)

1. all of the statues in the second room seemed out of place and did not match the houses interior. I also noticed that it looked like a kitchen cabinet with more macarons in it was put in the sitting room rather than in the kitchen.
2. Chess set on cafe table, the snake thing with wine attached to it. the boxes
3. All the weird statue type things: the warrior with shield; the planet type thing; the giant chess piece with the serpent round it; the horse statue; the shape statue next to the horse. And also the random sink opposite the shelves with boxes on. Two dining tables in one room and also two sofas back to back seemed strange. And the room with 2 tables and the armchairs seemed out of place.
4. there were 2 statue type things that seemed to float in the air between where walls might have been

Appendix G

Development of Main Themes In Qualitative Analysis

	Apartment	Museum
What helped you segment the space	• Function of the space • Having anchor points in the room which dictate purpose (bed=bedroom, toilet=bathroom) • Expectations of what rooms normally have in real life. • Stereotypes of normal rooms • Grouping of objects together, what you would expect to see in one room	• A lot of uncertainty • Objects which would have been on walls (paintings mostly) • Objects needed locations to hang from (a sink connected) • There is a level of insecurity about what the spaces actually were, why some of the objects were in their location, they must have been grouped for a reason • Large objects cant be across two different rooms, so they must be within one room with other objects • A lot more working out focused and practicality orientated, less so about what they thought the space actually was, or the confidence to outline a space
Did anything seem out of place	• Some responses didn't think anything was out of place • Those that did were mostly towards an extra shower and toiler (designed to be an ensuite, but lack of expectation means that they might not have been prepared for it) • Multiple responses acknowledge some objects seemed out of place until they drew in the walls, then it made sense	• A lot more variance in what seemed out of place in comparison to the apartment • Lack of a pattern, some saying the sculptures, some saying boxes, the dining area etc. A less concrete perception of the spaces and what function they might have served/their purpose. • Whole spaces seemed out of place (a kitchen in an art gallery) • Where with the apartment it was maybe one or two objects per participant, each participant had a longer list of what seemed out of place • No one said nothing was out of place

Main themes

- Categorisation and understanding of space
- Uncertainty and focusing on physical constraints
- Confidence in clarity
- Lack of clear spaces brings uncertainty and confusion

Appendix H

Additional analysis for Experiment 1

We used a 2x2 ANOVA to investigate the effect of boundary condition (open and doorway space), and time (immediate testing or testing after one week) on recognition performance. Results indicated a significant effect of boundary condition, $F(1,35) = 7.18, p = .01$.

However, a significant effect was not observed for time condition $F(1,35) = 1.23, p = .28$, nor was there a significant interaction between boundary condition and environment, $F(1,35) = .215, p = .65$.

We also used a 2x2 ANOVA to investigate the effect of boundary condition (shimmer and doorway space), and time (immediate testing or testing after one week) on recognition performance. Results indicated a significant effect of boundary condition, $F(1,35) = 5.69, p = .02$. However, a significant effect was not observed for time condition $F(1,35) = 3.48, p = .07$, nor was there a significant interaction between boundary condition and environment, $F(1,35) = .08, p = .78$.