The Domain Dichotomy theory: Exploring familiarity in Associative Recognition using behavioural studies and functional magnetic resonance imaging.

A thesis submitted to the University of Manchester for the degree of Master of Philosophy in the Faculty of Human and Medical Sciences

2012

Adrian Hugh Roper

School of Psychological Sciences
Table of Contents

Abstract ................................................................. 4
Declaration ................................................................ 5
Copyright Statement .................................................... 6
Chapter 1: Introduction .................................................. 7
    An introduction to Memory ....................................... 7
    The Medial Temporal Lobes ...................................... 12
    Recognition Memory and Associative Recognition Memory ................................................. 18
Chapter 2: Behavioural Research ................................. 32
    General Introduction .............................................. 32
    Part 1: An exploration of Auditory Stimulus preparation, recognition rates for different kinds of stimulus and associative recognition memory for auditory versus visual pairs. ... 40
    Pilot Study 1. Auditory Stimulus Selection .................. 40
        Introduction ....................................................... 40
        Method ............................................................. 41
        Results ............................................................. 43
        Discussion of Auditory Stimulus preparation .......... 45
    Pilot Study 2. Recognition Memory for different kinds of stimuli ........................................ 48
        Introduction ....................................................... 48
        Method ............................................................. 51
        Results ............................................................. 61
        Discussion ........................................................ 66
    Pilot Study 3: Auditory associative recognition ............ 69
        Introduction ....................................................... 69
        Methods ........................................................... 72
        Results ............................................................. 75
        Discussion ........................................................ 78
        General discussion of Part 1 ................................. 84
    Part 2: ................................................................ 85
        Associative Recognition Memory for different kinds of pairs: Matched Conditions ........ 85
        Introduction ....................................................... 85
        Method ............................................................. 88
        Results ............................................................. 94
        Discussion ........................................................ 106
Chapter 3: An fMRI study of familiarity for different kinds of stimulus items ........................... 117
    Introduction .......................................................... 117
    Method ................................................................. 125
    Results .................................................................. 130
    Discussion ............................................................. 142
Chapter 4: General Conclusions and Future Work ... 150
    Chapter 2: The behavioural tests ............................... 150
        Part 1 ................................................................. 150
        Part 2 ................................................................. 156
    Chapter 3 ................................................................ 159
    Conclusion .............................................................. 164
Abstract

The University of Manchester
Adrian Hugh Roper
Master of Philosophy

The Domain Dichotomy theory: Exploring familiarity in Associative Recognition using behavioural studies and functional magnetic resonance imaging.
August 2012

There has been a long running dispute about whether the medial temporal lobes show functional differentiation with respect to how they support recognition memory for items and associations. Most researchers believe that item recognition is supported by both recollection, a form of cued recall, and familiarity, a raw feeling of memory for an encoded stimulus that involves no recall. The Domain Dichotomy theory postulates that the parahippocampal and perirhinal cortices create memories for context and items respectively that support only familiarity, not just for their individual stimulus inputs, but also for associations between any inputs that they process (within-domain associations) into either intra-'item'/context associations or inter-'item'/context associations, although this distinction cannot currently be sensibly tested. In contrast, the hippocampus supports recollection for associations between inputs that only converge within its borders for binding into memories (between-domain associations). This view is fiercely disputed.

In this thesis, behavioural experiments are described that find that, apparently, between- as well as within-domain associations show high levels of familiarity support at test. This conflicts with the Domain view’s behavioural account of what within- and between-domain associations are, but not necessarily its neural definition of these concepts. Levels of recognition for different kinds of auditory association were extremely low and it was hard to compare these with visual associations without major confounding factors interfering. A functional magnetic resonance study was used in order to investigate continuous recognition for twice presented visual stimuli in six different categories (scenes, faces, words, animal pictures, tool pictures, and abstract art) with familiarity memory being assessed via a familiarity only procedure. This study found that familiarity for each of the categories of stimuli activated overlapping extra-medial temporal lobe regions very similar to those that Montaldi et al., (2006) found in a different familiarity only study of scene memory. Most importantly, there was an overlapping perirhinal cortex region deactivated by familiarity (relative to novelty) for stimuli from all six categories studied. It is predicted that associations between any combination of these stimuli will be supported by familiarity, which will deactivate a similar region of the perirhinal cortex. Future work needs to improve the design of similar imaging studies and to examine associations also between items and their temporal and spatial features, as well as looking at associations for inputs of different sensory modalities.
Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.
Copyright Statement

i. The author of this thesis (including any appendices and/or schedules to this thesis) owns certain copyright or related rights in it (the “Copyright”) and s/he has given The University of Manchester certain rights to use such Copyright, including for administrative purposes.

ii. Copies of this thesis, either in full or in extracts and whether in hard or electronic copy, may be made only in accordance with the Copyright, Designs and Patents Act 1988 (as amended) and regulations issued under it or, where appropriate, in accordance with licensing agreements which the University has from time to time. This page must form part of any such copies made.

iii. The ownership of certain Copyright, patents, designs, trade marks and other intellectual property (the “Intellectual Property”) and any reproductions of copyright works in the thesis, for example graphs and tables (“Reproductions”), which may be described in this thesis, may not be owned by the author and may be owned by third parties. Such Intellectual Property and Reproductions cannot and must not be made available for use without the prior written permission of the owner(s) of the relevant Intellectual Property and/or Reproductions.

iv. Further information on the conditions under which disclosure, publication and commercialisation of this thesis, the Copyright and any Intellectual Property and/or Reproductions described in it may take place is available in the University IP Policy (see http://www.campus.manchester.ac.uk/medialibrary/policies/intellectual-property.pdf), in any relevant Thesis restriction declarations deposited in the University Library, The University Library’s regulations (see http://www.manchester.ac.uk/library/aboutus/regulations) and in The University’s policy on presentation of Theses.
Chapter 1: Introduction

An introduction to Memory

Memory is the ability to encode, store and retrieve information. This allows an organism to learn from previous behaviour and situations. Traditionally, memory was considered unitary in the sense that there was thought to be only one kind of memory, i.e., only one kind of memory processing and only one brain system that supported memory. This idea was first dismissed following revelations (early in the second half of the twentieth century) that short-term memory fundamentally differed from long-term memory (Tulving, 2001). Since then, a series of additional divisions have been found, splintering memory into a series of, largely, independent forms of long-term memory. It was the discovery of the independence of declarative (explicit) and nondeclarative (implicit) memories, as demonstrated by the pattern of memory breakdown shown by the famous amnesic patient, H. M., that confirmed the presence of multiple memory systems (Milner, Squire, & Kandel, 1998). Declarative (explicit) memory and nondeclarative (implicit) memory differ in the ability of the individual to articulate (declare) the memory, which is only possible if rememberers show awareness that they are remembering. In other words, declarative memory can be articulated only because there is that awareness, whereas nondeclarative memories cannot because there is no such awareness. This difference has, historically been referred to as the difference between ‘knowing that’ and ‘knowing how’ or ‘memory with and memory without record’ (Squire, 2004b).

H. M., failed on delayed matching and delayed comparison tasks (what would now be considered standard tests of explicit memory), but he was able to learn new skills, such as the mirror-drawing task (Squire, 2004b). H. M., exhibited the classic amnesic syndrome of showing a
significant (indeed preserved) ability to learn a motor task and yet showed no memory of having practised it before. Following these developments, several decades of intense research sought to further define and classify the memory systems of the brain using the methods of the new field of cognitive neuroscience; this combines work on neuroanatomical structure, neuropsychology, cognitive psychology and computational science (Milner, et al., 1998). All this work has strongly suggested that there are several kinds of memory, each of which is supported by specialised brain systems. These are outlined in Figure 1. Although these kinds of memory may overlap between different systems, each has some brain systems that support only it. For example, lesion studies have shown that organic amnesia is a disorder of declarative memory in which many other kinds (perhaps all) of memory are preserved whereas differently located brain lesions that leave declarative memory intact disrupt other kinds of memory, such as conditioning, habit and skill memory, priming and non-associative learning.
The taxonomy details the broad spectrum of ‘types of memory’ or ‘memory systems’ demonstrating the relationship of declarative memory to the nondeclarative memory systems (from Milner, et al., 1998).

As discussed above, memory, no longer considered a unitary ability, can be divided into short-term (commonly described now as working memory) and long term memory. With regard to long-term memory, a hierarchical structure has been described. The following is an overview of the current, generally accepted, taxonomy of human memory. At the highest level of the hierarchy, long-term memory can be divided into nondeclarative and declarative memory. Under the umbrella of nondeclarative memory several distinct forms of implicit memory (for which there is no aware feeling of memory) have been identified including: procedural memory (skills such as riding a bike); priming (enhanced processing of stimuli given prior exposure, without conscious awareness that one is showing memory for the stimuli); classical conditioning (simple stimulus-response learning between originally neutral stimuli and specific responses) and nonassociative learning, which is illustrated by habituation to simple stimuli, such as traffic noise, in which repetition of the stimulus leads to a gradual decrease in the strength of an initially strong response, like orienting.
The amnesic syndrome, in which preserved nondeclarative memory is accompanied by impaired declarative memory, is currently best understood as resulting from damage to the medial temporal lobes or structures closely connected to them (discussed below). In contrast, nondeclarative memory is thought to depend principally on extra-medial temporal lobe structures that do not form part of the ‘amnesia structure memory system’. In fact, many forms of nondeclarative memory can be found in lower (invertebrate) animals entirely lacking medial temporal lobe structures (Milner, et al., 1998). Procedural skills seem to rely upon organisation of complex somatosensory representations and appropriate motor responses by the striatum (Graybiel, Aosaki, Flaherty, & Kimura, 1994). Priming has been proposed to rely upon a variety of different regions of the cerebral cortex, depending upon the sort of material being primed (Tulving & Schacter, 1990). Finally, motoric Pavlovian conditioning, a kind of classical conditioning, has been found to be mediated by the cerebellum (Thompson & Krupa, 1994). Nonassociative learning is thought to occur at a basic and general neural level. For instance, the repetition of a stimulus gradually reduces the rate and strength of neural firing in response to that stimulus.

Declarative memory is split into semantic memory, which is memory for facts and concepts, and episodic memory which is memory for personally experienced events. The relationship between semantic and episodic memory has been hotly debated (Squire & Zola, 1998; Tulving, 2001). For instance, Tulving and Markowitsch (1998) saw “episodic memory as a unique extension of ‘semantic memory’” while Squire and Zola (1998) saw the two as parallel subsystems of declarative memory. Some research has found apparently preserved semantic learning in amnesic patients while others have argued this might be the result of some remaining episodic memory (Squire & Zola, 1998; Vargha-Khadem et al., 1997). Irrespective of the precise relationship between episodic and semantic memory, there is little doubt that episodic memory is highly dependent on the integrity of the medial temporal lobes.
As mentioned, the amnesic syndrome is thought to be caused by damage to a system of brain structures that includes the medial temporal lobes and other structures that are connected to it, such as the retrosplenial cortex, certain nuclei in the midline diencephalon and fibres, like the fornix, that links this system of structures together. Patient H. M., had undergone a bilateral resection of the medial temporal lobes to relieve severe epilepsy which had a profound impact on his memory while sparing his other cognitive and memory abilities (Scoville & Milner, 1957). The hippocampus was focussed upon in this paper in contrast to the amygdala, which later work showed did not result in amnesia when removed. Initial attempts to replicate these findings in animals failed (Squire & Zola-Morgan, 1991). This was likely the result of using tasks that were possible to solve using one or more of the kinds of memory preserved despite medial temporal lobe lesions. It also reflected the difficulty in drawing parallels between animal memory problems and human amnesia, the characteristics of which were only partially understood. In initial examinations of animal amnesia, attempts were made to replicate the lesions of H. M., which included lesions of the hippocampus, amygdala and the surrounding cortices. It became apparent, however, that when only the hippocampus and surrounding cortices were damaged (sparing the anterior portion of the entorhinal cortex, amygdala and cortices adjacent to the amygdala) episodic memory was less impaired than was the case when larger medial temporal lobe lesions were given (Mahut, Zola-Morgan, & Moss, 1982; Squire & Zola-Morgan, 1991). This research began the thorough examination of the specific contributions made to episodic memory by each of the component structures found within the medial temporal lobes and will be discussed at length below.

Finally, episodic memory can be subdivided in turn, albeit with some further debate (see Aggleton & Brown, 2006), into memory representations that can be well supported by a kind of cued recall called recollection and memory representations that can be well supported by
familiarity or, more loosely, by recognition. In general, recall is memory for information that has to be retrieved from cues that are either externally present or generated internally (which is usually and inappropriately referred to as ‘free recall’). Recollection is a recall-like form of memory in which a recognition stimulus acts as a cue for the recall of information associated with the stimulus when it was last encountered, so that the recalled ‘contextual’ information helps to diagnose that the stimulus has been studied/encountered and, therefore, has been recognised. In contrast, familiarity is memory that does not involve any cued recall, but in which there is a feeling of memory for a previously encoded stimulus. According to dual process accounts of recognition (for example, Mandler, 1980), recognition tests of different kinds are supported to varying degrees both by recollection memory and by familiarity memory. In contrast, according to this view, all recall tests are almost entirely driven by recollection-like memory. Although this dual process (or kind of memory) view is focussed on episodic memory, it seems very likely that recognition of semantic information depends on very similar kinds of recall and familiarity memory.

The Medial Temporal Lobes

Of all the regions in the brain, one in particular is critical for episodic memory: the medial temporal lobe. The medial temporal lobe is a complex and varied brain region that comprises a number of distinct brain structures. Murray and Wise (2004) argued that, in reality, the medial temporal lobes do not constitute a single functional system at all, but are made up from a collection of diverse brain structures with distinct evolutionary histories. Nonetheless, clear evidence suggests that the regions of the medial temporal lobe contribute at least complementary processing with regard to memory. The regions of the medial temporal lobes include: the hippocampus; the amygdala; and the entorhinal, perirhinal, and parahippocampal
cortices. Each of these components can further be broken down into distinct parts. For instance, the hippocampus includes the different parts of the subiculum, the dentate gyrus, and the four fields of the cornu ammonis, CA1-CA4. All of these regions are thought to be critically involved in associative forms of declarative memory. However, the amygdala’s role in memory has been found to be limited to emotional stimuli and it is rarely considered in the majority of studies because they intentionally use stimuli that are emotionally neutral (Kensinger & Schacter, 2006).

Two important features of the medial temporal lobe are (1) the broadly hierarchical nature of the interconnections between its sub-regions with the hippocampus at the top of the hierarchy, which relates to its likely functions (Lavenex & Amaral, 2000), and (2) the broadly different cytoarchitectonics of its structures with the hippocampus having a mainly paleocortical, three layered structure and the perirhinal, entorhinal and parahippocampal cortices having a six layered neocortical structure (the amygdala has a completely different nuclear subcortical structure).

An overview of the region’s interactions follows. Sensory inputs from the neocortex converge in the perirhinal and the parahippocampal cortices. These regions channel the inputs into the entorhinal cortex and this, in turn, connects with the hippocampus. The inputs are then fed backwards through the system returning to the neocortex. However, these return links do not mirror the original paths. One example of this is that different regions of the hippocampus receive projections from specific parts of the entorhinal cortex but these regions project back to different entorhinal regions. This is also the case with the other medial temporal lobe components. These paths represent a hierarchy that involves increasing integration and complexity as the signals converge (Lavenex & Amaral, 2000). Whilst this description captures the essence of the medial temporal lobe system, it fails to describe its full complexity. In order fully to inform cognitive theories a more detailed outline is needed. A schematic diagram of information processing within the medial temporal lobes is outlined in Figure 2.
Figure 2. A diagram of information processing within the medial temporal lobes.

A schematic diagram of the input and convergence of information in the medial temporal lobes (from Montaldi & Mayes, 2010). NC-Neocortex, PrC-Perirhinal cortex, PhC-Parahippocampal cortex, ErC-Entorhinal cortex, Hp-Hippocampus. A,B,C and D represent different kinds of information. + ? indicates the absence of precise knowledge.

The perirhinal and parahippocampal cortices receive a large number of converging signals from unimodal and polymodal associational cortices. Particularly in humans, the majority of these cortical inputs are from visual areas, but these two neocortical medial temporal lobe regions receive different types of information. The perirhinal cortex acts as the terminating point for the ventral visual stream which is associated with the processing of visual object information. In contrast, visuospatial information is channelled to the parahippocampal cortex from the dorsal stream. Other modalities also converge within these regions. Somatosensory processing cortices project to both the perirhinal cortex and parahippocampal cortex and the auditory association cortex links with the parahippocampal cortex (Suzuki & Amaral, 1994). While a
separation of inputs exists, there are many associational connections between the perirhinal cortex and the parahippocampal cortex.

The perirhinal cortex and the parahippocampal cortices serve as the principal, but not the only, sources of input to the entorhinal cortex. Whilst they input to different sections, the entorhinal cortex also receives significant extra-medial temporal lobe neocortical projections. The entorhinal cortex has a large number of intrinsic associational connections, allowing further integration of signals to take place. In addition, the neurons of the entorhinal cortex can be separated into three distinct groupings: lateral; medial; and mid-mediolateral regions (Dolorfo & Amaral, 1998). The associative connections found in the entorhinal cortex tend to link with other neurons within that region of the entorhinal cortex, with fewer connections between the regions. This relative isolation of neural connections is emphasised by the selective inputs and outputs of the entorhinal cortex.

For instance, signals entering the mediolateral portions of the entorhinal cortex will be transmitted, almost solely, to specific regions of the septotemporal dentate gyrus (Dolorfo & Amaral, 1998). Neocortical inputs that enter the entorhinal cortex in the dorsolateral and caudomedial regions transmit to the septal half of the dentate gyrus, while subcortical structures that enter the rostroventral portions of the entorhinal cortex project to the temporal levels of the dentate gyrus. This might be a way of facilitating parallel, or differential, processing within the hippocampus. Such a theory has been supported by at least one study that found that damage to the septal portions of the rat hippocampus resulted in reduced spatial learning, whereas damage to the temporal regions did not (Moser, Moser, & Andersen, 1993). The intrinsic associative connections suggest that the entorhinal cortex is responsible for more than just transmitting signals to the hippocampus. While it is often thought of as linking the perirhinal and parahippocampal cortices with the hippocampus, it also receives additional inputs, for instance
from the amygdala. Nonetheless the selectivity of the associative connections within the entorhinal cortex point towards a directed channelling of incoming signals to different regions of the hippocampus. This may be critical for hippocampal functioning.

The highest level of processing in the hierarchy is the hippocampus. Within the hippocampus it is clear that there are several cytoarchitectonically distinct structures. There has been ongoing debate as to which structures should be included when describing the hippocampus. Here, it is defined as the dentate gyrus, CA1, CA2, CA3 fields, and the different components of the subiculum.

One of the ways in which the cytoarchitectonics of the hippocampus differs from that of the six layered neocortex is in its pattern of reciprocal connections. That is to say, generally, a region in the neocortex projecting to another will receive return projections. However, this is not necessarily the case in the hippocampus. An illustration of this is the series of connections from the dentate gyrus to CA3, to CA1, and subsequently, to the subiculum without parallel return pathways being present.

This linear progression may suggest that there is a similar sequential flow of information. However, the picture is less clear when an abundance of minor links, in conjunction with the most prominent connections, are considered. For example, the same regions of the entorhinal cortex that project to the dentate gyrus also project to CA3, albeit to a lesser degree. This suggests that processing may not be purely serial in nature and is shown by findings that CA1 (which is downstream of the dentate gyrus) can show normal activity after pharmacological deactivation of the dentate gyrus. This CA1 processing is supported by direct connections from the entorhinal cortex that bypass the dentate gyrus and CA3.
The fact that the hippocampus receives a great variety of highly processed multimodal sensory information sets it apart from the majority of other brain regions. It also has a large number of intrinsic connections that allow it to compare and contrast incoming signals. These qualities, which enable it to integrate information from all sensory modalities and process information in a serial fashion, may be a unique attribute vis-à-vis other brain regions (Andersen, Morris, Amaral, Bliss, & O'Keefe, 2007). This suggests that not only is it special with respect to the range of kinds of information that it receives, but it also processes this complex input in a very special way that would not be shown by neocortical structures if they received the same inputs. In other words, it seems likely that the hippocampus processes different information in a somewhat different way from the neocortical perirhinal and parahippocampal regions of the medial temporal lobes.
Recognition Memory and Associative Recognition Memory

There are different theoretical positions about the role of the medial temporal lobes in declarative memory. These differences have particularly related to recognition memory, which has often been studied using memory for items. The main theories of how the medial temporal lobes support this kind of memory have fallen into two camps. The first kind of theory proposed that the medial temporal lobes functioned in a relatively homogeneous fashion with respect to item recognition memory and that, while the different structures might vary in their activity for different types of stimulus or how ‘strong’ the item recognition memory was, there are no qualitative differences in this activity across the medial temporal lobe structures (Squire, 2004a). In contrast to this position, some researchers held that different medial temporal lobe structures make qualitatively distinct contributions to item recognition memory (Yonelinas, 2002b). Although the details of how their functions differed varied from researcher to researcher, these kinds of theories all suggested that different medial temporal lobe structures supported familiarity and recollection, which it was argued are the two kinds of memory that support item recognition as suggested by Mandler (1980). In contrast, the first kind of view argued that the various medial temporal lobe structures mediated familiarity and recollection in a homogeneous fashion (Squire, Wixted, & Clark, 2007), although they were functional heterogeneous in ways that were only vaguely expressed, but probably involved different medial temporal lobe structures processing different kinds of information.

Familiarity and recollection are often used without fully specifying what is meant by their use. This lack of clarity can cause problems. Within the context of recognition memory, recollection is the recall of information (cued by the recognition stimulus) which is in addition to that being presented. This additional information was experienced during the study episode and
is associated with the memory for the given stimulus. For instance, the presentation of a given
stimulus might cue recall of what was thought about when that stimulus was studied earlier.
Given the unique nature of the association formed at study, the sort of recollection is highly
diagnostic of prior occurrence of the item and should lead to strong and accurate recognition.
Familiarity, in contrast, is a feeling of memory for a given stimulus in the absence of any
additional recollection. Re-encoding a given stimulus fails to cue any additional memory while
simultaneously producing a feeling of memory. Familiarity and recollection, therefore, differ in
two key ways. The first difference is the presence, or absence, of recall (only in recollection) and
the second difference is what the information is for which there is memory (only the stimulus in
familiarity while recollection involves additional material which was associated with the stimulus
at study).

The statistical relationship between familiarity and recollection has yet to be made concrete
(Montaldi, Spencer, Roberts, & Mayes, 2006). Identifying this correctly is critical for estimating
the amount of familiarity correctly. When an item is reported as familiar it has, generally, been
assumed that familiarity has occurred while recollection has not because, if it had, it would have
been reported as such. However, when an item is reported as recollected it is not clear whether
familiarity was also present. There are three general statistical relationships that have been
proposed to describe the relationship of recollection and familiarity: redundancy, exclusivity and
independence. According to the redundancy view, all recollection is accompanied by familiarity.
This means that, for example, familiarity hits are the same as recognition hits because they
include all responses where familiarity occurs on its own and all responses where recollection
occurs. Redundancy might occur because the processes underlying familiarity provide a
necessary condition for further processes that generate recollection to work. The exclusivity view
makes the opposite assumption to the redundancy view, i.e., that recollection always occurs
without familiarity and that familiarity always occurs on its own. This might occur if the
processes that generate recollection inhibit those that generate familiarity and vice-versa. Finally, according to the independence view, the likelihood of familiarity is equal whether or not recollection occurs even though its occurrence is very hard for people to determine if they have already recollected. Statistical independence might occur provided that familiarity and recollection each depend on overlapping but partially distinct processes, and that there is no net inhibitory or excitatory interaction between these distinct processes. If the view is correct as most researchers have assumed, then the proportion of familiarity responses within the recollection responses will be the same as the proportion of familiarity responses that occur in the absence of recollection. The proportion of familiarity hits and false alarms will, therefore, be equal to the proportion of unrecollected items felt to be familiar from the studied and unstudied stimuli respectively.

As indicated above, different positions about how recognition memory is supported and how this relates to the functions of the different structures of the medial temporal lobes have evolved in the last few years. A general consensus has emerged that there must be some variation in function amongst the structures even if the variables which modulate that variation have yet to be specified (Squire, et al., 2007). There has also been a shift in theoretical thinking and research to include not only the functional and neural mechanisms that underlie item recognition memory, but also those that include the functional and neural mechanisms underlying associative recognition memory. Associative recognition memory is memory for the association between two or more components. Associative recognition tasks involve the study of and subsequent testing of pairs of stimuli (i.e., A-B, C-D, E-F where A to F might be words, faces, object pictures, scenes etc.) including original pairs and recombinations such as (C-F). The use of recombined pairs of original items prevents the memory for component items being diagnostic of an original pairing so that accurate performance can only be driven by memory for the association itself. In human research, tests often employ pairs of items displayed on screens.
However, tests that tap associative recognition memory for items’ spatial positions or for their temporal position have also been used. So, associative recognition tests can tap memory for associations between similar or different kinds of items or memory for associations between items and their spatial or temporal positions, or associations between items and other aspects of their context.

Medial temporal lobe dual process theories include several similar, but distinct, theoretical positions that propose that the hippocampus is responsible selectively for item-triggered recollection whereas the perirhinal cortex is responsible selectively for item familiarity (for example see Brown & Aggleton, 2001). When these theories are extended to include associative recognition memory, it has nearly always been assumed that whereas recollection (dependent on the hippocampus) can support all kinds of associative as well as item recognition, that familiarity (dependent on the perirhinal cortex) can only support item recognition (see Montaldi & Mayes, 2010 for comments). It has been generally assumed that recollection of study-context information can be cued by associations as well as items, but that familiarity is only accurate if it is felt for studied items. However, the reasons given for this dominant view have not been particularly compelling because it certainly seems that we can experience that two or more items feel as if they have gone together in the past even when we are unable to recollect anything about these previous associated occurrences. This dominant view about associative recognition, therefore, has to assume that, although familiarity for item associations may occur, it cannot accurately discriminate between previously experienced associations of items and ones that have never previously been experienced (or at least not experienced in the study context if a psychological experiment is being considered).

This dominant view about associative recognition does, however, allow familiarity to support associative memory at above chance levels of accuracy for one specific kind of
association. This is the kind of association that is formed when two or more previously distinct stimuli have been unitised as a result of study. Unitisation is the fusing of component items of an association into a single mnemonic representation in which the components are subjectively felt to be one item rather than two or more items that were previously paired together. According to the model, if a separate unitised representation of the two items is formed, then this single memory should be capable of being found familiar. In this way, familiarity should support memory for the pair in the absence of recollection in a way that it cannot support recognition for pairs of items that have not be unitised (i.e., inter-item associations). Studies have shown that, for those pairs that have been claimed to be unitised, this seems to be the case. Rhodes and Donaldson (2007) conducted a study where the Event-Related Potential (ERP) correlates of familiarity and recollection were examined under three conditions. In all three conditions, two words were paired at study but the nature of this pairing was manipulated. At study, words were paired in a pre-existing association without a semantic relationship (traffic-jam), a pre-existing association with a semantic relationship (lemon-orange), or a semantic relationship without a pre-existing association (cereal-bread). At test, all three types of association elicited neural correlates of recollection but, in the case of the pre-existing association (without an additional semantic relationship), the neural correlate of familiarity was also found. The selective way in which an ERP familiarity correlate was found only for pairs that were pre-existing associates was explained in terms of participants’ subjective ratings. Pairs that were pre-existing associates were most likely to have been experienced as single units, i.e., unitized. This finding supports the idea that when two or more items are felt to be strongly unitised in the sense that they are experienced as a single item during the recognition memory test, familiarity can successfully support such memory.

The previous finding highlights an unfortunate aspect of the concept of unitisation: there currently exists no agreed upon objective method of assessing the presence, or degree, of
unitisation. Subjective criteria can be used when there are large differences between two conditions, but, in most cases, felt differences may be unreliably small or undetectable. Two possible methods of identifying when unitisation has occurred are tracking changes in reaction times at test or charting variation in the memory performance for the component items. Reaction time may be faster when identifying unitised pairs, with speeds comparable to item memory, although it is not established whether any significant differences that appear can be validated by determining whether pairs felt to be single items are also judged old faster than pairs felt to be associations between two or more items. In doing this, care will need to be taken to ensure that recognition levels are matched between stimuli felt to be single items and those felt to be associations. Testing the effect unitisation might have on recognition memory for the components of the studied pairs is more likely to prove successful, although examining this will also require levels of recognition memory to be matched for pairs felt and not felt to be single items. If a memory of the unitised pair is formed, it is possible that memory for the component items would be lower because the unitised stimulus is experienced as a Gestalt. Experienced outside the Gestalt, individual stimuli might feel less familiar. This should produce significant differences in recognition memory for the components of those stimuli that were encoded as units at study and those that were encoded as inter-item associations. However, both these possible objective criteria require that levels of associative recognition are matched between two kinds of recognition when the aim is to determine whether one involves more unitised associations than the other. Also, with respect to the second possible objective criterion, it could be the case that the direct associative links that support inter-item associative recognition familiarity may lead to poorer item familiarity because associative and item memory encoding work in competition with each other. If this was so, this criterion would not be validated by comparable subjective judgements of the degree of unitisation.
There is, therefore, a problem in determining whether two or more items have been unitised. Given this problem in determining whether an association is intra-item (unitised) or inter-item (not unitised), particularly if unitisation is viewed as not all-or-none but a matter of degree, it is very hard to exclude the possibility that associative familiarity can support inter-item associations at well above chance levels of accuracy, i.e., so that the associative familiarity hit rate is significantly above the false alarm rate. The result has been that most theorists have simply assumed without proper evidence that when familiarity successfully supports associative recognition this is because unitisation has occurred. However, one theory, the Domain Dichotomy model, has claimed that associative familiarity can accurately support any kind of inter-item association (Mayes et al., 2007; Montaldi & Mayes, 2010). Other theories have made no explicit statement about the ability of associative familiarity to support inter-item associative recognition, and, given the dominant view, this comes close to denying that associative familiarity can support any kind of inter-item association. One such theory is the Binding of Item and Context (BIC) model (Diana, Yonelinas & Ranganath, 2007). The BIC model emphasises not so much the memory processes that support kinds of memory, such as familiarity, but more the informational content of items and associations. It is also a theory about how the medial temporal lobe structures support different kinds of recognition memory.

The BIC model argues against a simple mapping of familiarity and recollection to certain structures and emphasises instead, the specific demands of the task and the type of information involved (Diana, Yonelinas, & Ranganath, 2007; Ranganath, 2010). Despite this, and in keeping with other dual process theories of recognition, BIC continues to associate the perirhinal cortex with specific item information and the hippocampus with some sort of associative memory that is referred to as relational memory to stress the flexibility of this kind of memory. In addition to these two structures, the model also includes the proposal that the parahippocampal cortex is responsible for memory of context. Once this has been stated, the role of the perirhinal cortex
and parahippocampal cortex appear as the two fundamental memory sites for items and general context. In the model, context does not only include spatiotemporal information, but other information, although this aspect of the model still needs to be more clearly and fully specified. It is the hippocampus that associates this item and context information, producing the rich episodic memories that reflect human experience.

The BIC theory is drawn, principally, from a mixture of neural structure and functional imaging studies. As noted above, in the description of the medial temporal lobes, the perirhinal cortex is the primary recipient of the ventral visual stream (associated with item information) whilst the parahippocampal cortex receives input from the dorsal visual stream (associated with more spatial information). The model also reflects fMRI findings that, over many years, have consistently shown perirhinal activations/deactivations for item memory and parahippocampal activations ascribed to recollection responses (in addition to hippocampal activations). Recollection, as defined earlier, involves the stimulus being recognised cueing the recall of ‘contextual information’ from previous encounter with the stimulus that helps confirm it is ‘old’. The model makes several unique predictions concerning how the medial temporal lobes should be seen to function when engaged in certain tasks. In particular, the model predicts that familiarity memory of item information should show activity isolated to the perirhinal cortex whereas recollection of association of items (which by definition includes memory of context) should show activations in perirhinal cortex, parahippocampal cortex and the hippocampus. The perirhinal activations during recollection of association of items results from a reactivation of the item representation held in the perirhinal cortex trigged by recollection processes in the hippocampus.

In contrast to BIC, the Domain Dichotomy model makes explicit claims about the ability of associative familiarity to support certain kinds of inter-item associative recognition. These
claims are based in large part on findings with the patient, YR, who suffered relatively selective
damage to the hippocampus (Mayes, Holdstock, Isaac, Hunkin, & Roberts, 2002; Mayes et al.,
2004) as well as similar findings with other hippocampal patients (for example, see Vargha-
Khadem et al., 1997). YR not only showed very good item recognition in the face of impaired
recall, but also showed very good recognition of associations between pairs or triplets of items in
the same category (such as two words or two faces), but impaired recognition of associations
between pairs of components/items in different categories (such as an animal picture paired with
a written name of a profession, or a scene picture with a hard-to-verbalize sound, or a face and a
voice). This lesion evidence suggested that hippocampal lesions hardly affected within-domain
associative recognition, which is compatible with this kind of recognition being successfully
supported by familiarity as well as recollection whereas such lesions disrupt between-domain
associative recognition as badly as they disrupt recall, which is compatible with the suggestion
that this kind of associative recognition depends almost entirely on recollection, and is very
poorly supported by associative familiarity.

The model provides an anatomical/physiological basis for this distinction between
within- and between-domain inter-item associative recognition, which is based on how inputs are
processed by the structures of the medial temporal lobes. It proposes that inputs from pairs of
items of the same category are integrated in the perirhinal cortex. In accordance with other dual
process accounts, it claims that this neocortical structure creates memory representations that are
good at supporting familiarity, but very poor at supporting recollection because this cortex is
relatively poor at creating pattern separated memory representations. Such representations fail to
differentiate clearly between similar inputs (see Norman & O'Reilly, 2003). In contrast, between-
domain items do not converge for mnemonic processing within the perirhinal cortex, but only
do so within the paleocortical hippocampus, which creates memory representations that are
sparsely encoded and well pattern separated so that they are excellent at supporting recollection,
but very poor at supporting familiarity. Pattern separated representations even of very similar representations are very distinct from each other and this allows pattern completion, i.e., recollection to be well supported. These different kinds of memory representation are created because of the different cytoarchitectonics of the paleocortical hippocampus and the neocortical perirhinal cortex. The later refinement of the model (Montaldi & Mayes, 2010) takes account of the similar neocortical cytoarchitectonics of the parahippocampal cortex and accepts the proposal of the BIC about the role of this cortex in processing contextual information in order to suggest that the parahippocampal cortex receives contextual inputs and creates context memories that are very good at supporting context familiarity, but poor at supporting context-triggered recollection. Equally, the model proposes that the parahippocampal cortex supports familiarity memory for two associated contexts because these converge in this cortex to enable it to create a familiarity-supporting context-context associative memory.

Thus, the Domain Dichotomy theory (and its later refinement) makes predictions about the distinct effects of lesions upon and the distinct kinds of activation shown by all three medial temporal lobe structures (Mayes, Montaldi, & Migo, 2007; Montaldi & Mayes, 2010). While it adheres strongly to typical dual processing accounts that differentiate medial temporal lobe functions based upon their different contributions to familiarity and recollection, many of its claims are consistent with the BIC model. It differs in the following ways. For example, both models accept that the perirhinal cortex can support familiarity memory for item information, that the hippocampus is involved in recollection memory for all the associations that it binds into relational memory representations and that the perirhinal cortex (and familiarity memory) can support associative recognition memory when two items have been unitised. The unique contribution of the Domain Dichotomy model is its extension of the suggestion that the perirhinal cortex can support memory for inter-item associations when the components of the associations converge for processing within its structure and that in a similar way the
parahippocampal cortex can support accurate familiarity not only for a context, but also for associations between contexts. Although the model’s claims about within-domain and between-domain inter-item associations are based on its proposal that the components of these associations converge within the relevant neocortical structures, its fundamental claim is whatever associations converge within a neocortical medial temporal structure for mnemonic processing and integration will be supported by familiarity. If between-domain associations turn out to converge at these sites, then even these associations should be supported by familiarity successfully. In other words, the ultimate test of the Domain Dichotomy model is likely to depend on brain imaging (do some between-domain items/components converge in the perirhinal cortex or, for that matter, the parahippocampal cortex) rather than on behavioural demonstration of whether or not some between-domain associations support associative familiarity.

There are several problems with testing the Domain Dichotomy model. First is the difficulty in discriminating whether familiarity is of a unitised intra-item association or of a non- or at least less-unitised association because there are as yet no agreed objective criteria for deciding. This thesis cannot address this issue strongly because of this lack of agreement. However, it seems unlikely that, for example, two faces only encountered briefly on one or two occasions will subsequently be felt to be one higher level single item, particularly as participants in memory experiments report that they feel these two faces were experienced together earlier rather than they feel the stimulus is somehow unitised. If a stimulus is experienced as an item, people report that an item is familiar, but if they experience it as an association, then they report that it feels as if its components occurred together earlier.

A second major problem is that, as indicated above, familiarity is difficult to measure and there has been much controversy about this (for example, see Migo, Mayes, & Montaldi, in
A common way of measuring familiarity (as well as recollection) is to use the remember/know procedure (Gardiner, Ramponi, & Richardson-Klavehn, 2002; Yonelinas, 2002b) where participants report whether they have recollected an item or whether it only feels familiar. Unfortunately, even if familiarity is able to support associations of a particular type of pair in healthy control participants, there is no reason to assume that recollection could not, under some circumstances, dominate recognition memory for that association to such a degree that measuring familiarity is extremely unreliable because so few associations are unrecollected. This has been shown in the majority of traditional associative recognition tasks that have sought to identify which of the two kinds of memory (familiarity or recollection) accurately support recognition for pairs (Gardiner, 1988; Yonelinas, 1994). Several studies fail to find significant familiarity for word-word associations with the remember know procedure (Giovanello, Keane, & Verfaellie, 2006; Hockley & Consoli, 1999; Yonelinas, 1997). These studies found that familiarity for the within-domain associations was incapable of discriminating between studied and unstudied pairs (i.e., hit rate was not higher than false alarm rate).

Even so, the remember/know procedure has occasionally found that familiarity contributes a significantly higher proportion of overall recognition for within-domain associations than for between-domain pairs (Bastin, van der Linden, Schnakers, Montaldi, & Mayes, 2010; Mayes, et al., 2007). This kind of finding raises an important point about whether one should be comparing whether the familiarity score is absolutely higher for within-domain than for between-domain associations or whether it is more appropriate to compare the proportion of overall recognition consisting of familiarity is higher for within-domain associations. Many factors are likely to influence how rapidly acquired and how strong associative recognition actually is, and these do not have to be directly related to medial temporal lobe function. One such factor might be that typically people are much more practised at encoding between-domain associations-something that may well relate to a neocortically kind of
expertise. In an extreme case, between-domain associative recognition might be close to perfect whereas (for the same learning and test conditions) within-domain associative recognition might be at chance. It would be strange to argue that this contradicts the Domain Dichotomy model because absolute familiarity levels are higher for the between-domain associations. Nevertheless, it must be admitted that if within- and between-domain associative recognition levels are not matched when tested under similar conditions, there is the possibility of other confounds. For example, extra learning trials might help associative familiarity more than recollection. This should be borne in mind in interpreting the behavioural results to be described in this thesis.

One way of avoiding the problem that under certain conditions the levels of recollection will be so high as to make it impossible to measure familiarity either at all or at least reliably is to use a modification of the remember/know procedure that focuses on familiarity (Montaldi et al., 2006; Mayes et al., 2007). This familiarity-only procedure instructs participants to focus on rapid, but accurate familiarity judgements and not to try and recollect so that any recollection is involuntary. The aim is to get very low levels of such recollection so that measures of familiarity levels will be little affected of whether one assumes an independence, redundancy or exclusivity statistical relationship between recollection and familiarity. However, the procedure does not work unless great care is taken to ensure that levels of involuntary recollection are not too high. This can be done by choosing a method of encoding that boosts familiarity but not recollection or by testing after a long delay (see Montaldi et al., 2006).

The Domain Dichotomy theory makes unique predictions regarding the different contribution of familiarity to within-domain versus between-domain associative recognition memory, and also about the different contribution of the perirhinal cortex to these two kinds of association. In this thesis, several pilot studies and two experimental studies are described. The pilot studies examine the preparation of auditory stimuli and associative recognition performance
for pairs of auditory stimuli. In addition, item recognition for the components of subsequently used associations is also examined in order to determine whether there is a relationship between item and associative recognition levels when the components are shared. The first experiment is a behavioural one that compares recognition levels of various within-domain and between-domain tasks and also examines familiarity levels for many of these tasks. The experiment involves fMRI and examines one of the fundamental proposals of the Domain Dichotomy model, which is that components of within-domain associations converge within the same perirhinal cortex regions (contextual components were not examined in this study) for mnemonic processing and integration so as to produce a memory that can support successful familiarity. If familiarity for items in different categories of information affects perirhinal cortex activity, then this conflicts with a central claim of the model. If this is found, then it will be necessary in the future to test the fundamental claim of the model that any components that converge either within the perirhinal cortex (or possibly within the parahippocampal cortex) may have their associative recognition supported by familiarity successfully.
Chapter 2: Behavioural Research

General Introduction

There exist various dual process theories of recognition memory and, whilst they make differing predictions about how familiarity and recollection contribute to item and associative recognition memory, the theories did not initially propose that different medial temporal lobe subregions are involved in processing different kinds of information (Squire, et al., 2007; Yonelinas, 2002a). One of the first theories to advance this specific idea was the BIC theory of declarative memory, which makes specific proposals about which medial temporal lobe subregions process different kinds of information (Diana, et al., 2007). Various papers have been published that support the idea that different medial temporal lobe subregions will be activated, based not on whether recollection or familiarity is involved, but upon the class of stimulus being remembered (for example Awipi & Davachi, 2008). The BIC theory’s claims about functional differentiation of familiarity and recollection mediation within the medial temporal lobes are far less explicitly and clearly drawn, although the theory does indicate that the perirhinal cortex mediates item/object familiarity whereas the hippocampus is responsible for recollection and does not mediate item familiarity. In contrast, the Domain Dichotomy theory maintains that the roles of the hippocampus and perirhinal cortex differ because of their differing cytoarchitectonics as well as their differing inputs (Mayes et al., 2007). In its updated form (Montaldi & Mayes, 2010), this means that it states that the perirhinal cortex rapidly creates familiarity-supporting memory representations and is extremely poor at supporting recollection that is triggered by object/item information whereas the hippocampus solely supports all kinds of recollection because its cytoarchitectonics suit it for creating well pattern-separated memory representations that readily allow pattern completion. As well as proposing that within-domain inter-item associative recognition is supported by hippocampally-mediated recollection, the
Domain Dichotomy view also proposes, contrary to other theories, that this kind of associative recognition is supported by perirhinally-mediated associative familiarity.

At a deeper level, as outlined in the previous chapter, the Domain Dichotomy theory proposes that the region in which any two stimuli converge within the medial temporal lobe for memory processing will dictate whether familiarity or recollection is the kind of memory that primarily supports the associative recognition for the stimulus pair that is bound together in memory. Convergence of a stimulus pair for memory processing within the perirhinal cortex should lead to an association that is well supported by familiarity whether the association formed is between two items (an inter-item association), or involves a newly formed super-item when unitisation has occurred.

While the Domain Dichotomy theory is based upon an examination of the neural substrates of recognition memory, it also serves to explain the apparently puzzling finding that patients showed impaired associative recognition memory for some types of pairs but not for others (Mayes, et al., 2004; Vargha-Khadem, et al., 1997). In these studies, patients with selective hippocampal lesions seemed to show preserved associative recognition memory for pairs of stimuli that came from the same category, but not for those pairs that came from different categories. When the information is considered to be of the same category, these pairs are termed ‘within-domain’ and when they fall within different categories they are termed ‘between-domain’.

In the Mayes and colleagues and Vargha-Khadem and colleagues hippocampal lesion studies mentioned above, those associative pairings for which recognition was very impaired and which, according to the Domain Dichotomy theory, were not supported by familiarity memory, comprised visual pairings that were not drawn from the same category. Rather, they were drawn
from different categories so that a viewer would have regarded the paired stimuli as very
different from each other. Categories are intuitively defined and given labels such as ‘faces’,
‘tools’ and ‘abstract art’ on the assumption that people automatically recognise a given stimulus
as belonging to such a category. Insofar as it refers to kinds of association, the Domain
Dichotomy theory focuses on whether associated stimuli come from a single category or from
two or more distinct categories. The theory makes no specific claims about the properties of the
precise stimulus category or categories that make up an association. Nor does the theory claim
anything precise about the importance of how subjectively similar (in a conceptual or perceptual
way, or indeed both) two categories need be on a perceptual or conceptual similarity continuum
if associative recognition is to be well supported by familiarity. Instead, the theory emphasises
that the really critical claim is where stimuli converge within the medial temporal lobe for
memory processing. If that convergence occurs early in the perirhinal or parahippocampal
cortices, then, following rapid learning, recognition of the association will be well supported by
familiarity. In contrast, if convergence only occurs in the hippocampus, the learnt association will
only be well supported by recollection. To what degree the site of convergence depends on the
nature of the stimulus, its modality, or other, as yet undefined, qualities remains to be fully
determined.

Although it is still not fully known where different kinds of stimuli converge within the
medial temporal lobe and to what extent this is influenced by factors such as kind of encoding,
quite well supported claims have been made. In particular, the idea that any kind of object or
item stimulus is processed within the perirhinal cortex whereas ‘contextual’ stimuli are processed
within the parahippocampal cortex and only fully converge in the hippocampus is quite well
supported (Diana, et al., 2007; Ranganath, 2010). Another, less commonly considered, possibility
is that stimuli in different sensory modalities, such as visual and auditory stimuli, would converge
only in the hippocampus, whilst the convergence of two sets of, even very different, visual
stimuli (visual object stimuli being shown by countless studies to be supported by the perirhinal cortex) might converge earlier in the hierarchy and thus be supported by familiarity processes. Related to this is the possibility that the point of convergence within the medial temporal lobe and the level of support for associative recognition that is provided by familiarity may depend on how subjectively (or possibly even objectively) similar the associated stimuli are to each other. If auditory stimuli are used to investigate these ideas there, unfortunately, may be certain difficult-to-control problems that make comparisons of findings between within-modality and between-modality associations very difficult. For example, auditory stimuli cannot be presented simultaneously, unlike visual stimuli. This makes their encoding somewhat distinct and it may transpire that auditory stimuli are more difficult to recognise as items, as well as associations, when compared to visual stimuli. Moreover, any behavioural study of within- or between-domain pairs that seeks to assess whether recognition memory for those pairs is supported by familiarity suffers from two further problems.

The first problem is that good measures of subjective ‘similarity’ have yet to be confidently identified and then related to other behavioural measures (such as familiarity levels) and to their neural underpinnings. If where in the medial temporal lobe any two kinds of stimuli converge is to any degree a function of their level of similarity, this will be very hard to ascertain unless we can identify criteria that are reliable and independent of how much familiarity is available to support such stimuli. Without the availability of such criteria, there is a risk of circular reasoning according to which those pairs apparently supported by familiarity are deemed to be similar and those that are not supported by familiarity are considered to be dissimilar.

The second problem relates to the potential for any given stimulus type to be more or less difficult to recognise whether using recollection, familiarity, or both. Different studies of associative memory have used different types of stimuli. It is a hidden assumption that the levels
of item recognition for each type of stimulus used is the same in order for there to be no significant impact of item recognition ease on associative memory performance. Only if item recognition performance for different types of stimulus is sufficiently similar is it possible for sensible comparisons of associative recognition to be made. This would only be untrue if associative recognition was completely independent of item recognition, which seems unlikely because memory for an association seem to entail that one has memory for what is associated unless associative information has been unitized. If, within a pair of items, memory for one or more of the components is close to chance, owing to the difficulty in remembering items from that type of stimulus, associative recognition memory should also be near chance. Equivalent levels of item recognition for two kinds of association may only be possible after considerably more training for some of the component items. Additional exposure to a given stimulus represents a confound in conventional memory experiments making this procedure potentially problematic. As with other manipulations, there is no guarantee that additional training trials will change item and associative recognition to the same degree. Perhaps this makes comparisons of associative recognition tricky, but one should aim to determine how much associative recognition, recollection and familiarity are affected by factors such as item recognition, recollection and familiarity. Exact equivalence in item recognition need not be present. However, levels should be reasonably close. In order to quantify this potential confound the level of item memory for stimulus types employed in testing associative recognition memory should be assessed. Nonetheless, it should also be remembered that, although item recognition will be an important determinant of associative recognition, there are likely to be many more still poorly identified factors that influence associative recognition levels in addition to those postulated by the Domain Dichotomy theory.

This chapter is divided into two parts. The first part comprises three pilot studies which seek to explore the feasibility of using auditory stimuli in item and associative recognition tests. If
auditory stimuli can be paired with visual stimuli in associative recognition, this would provide what the Domain Dichotomy theory describes as between-domain associations. These can be contrasted with auditory-auditory and visual-visual within-domain associations, about which the theory makes different predictions. The pilot work will also examine whether recognition levels for associations involving auditory stimuli in contrast with visual stimuli may be negatively influenced by relatively poor levels of item recognition for those materials. The chapter’s second part consists of a behavioural experiment exploring associative recognition memory for different kinds of visual pairs containing within- and between-domain associations. The main aim is to test the Domain Dichotomy theory’s prediction that familiarity will support within-domain associative recognition far more effectively than between-domain associative recognition. As a whole, Part 1 identifies certain difficulties pertaining to the use of auditory stimuli. This leads to the decision not to include such stimuli in the main experiment reported in Part 2 of the chapter because a prolonged development period would be necessary to ensure that the use of such stimuli would lead to interpretable results. Part 1 goes on to assess the relative similarity of item memory for a variety of stimulus categories under recognition conditions. Finally, Part 2 produces novel evidence that, under some conditions, when absolute measures are used familiarity seems to support between-domain pairs better than within-domain pairs but when familiarity is calculated as a proportion of recognition memory, familiarity supports between-domain at least as well as within-domain associative recognition memory.

Part 1.

The first pilot study explored the preparation of auditory stimuli with semantic content [subsequently referred to as environmental sounds] and examined to what extent such stimuli can be interpreted correctly by people and whether there is interpersonal agreement about these
interpretations as there would be with meaningful visual stimuli, such as pictures of animals, tools and scenes. The need for ‘Meaningless’ auditory stimuli is also discussed and these are compared with other kinds of visual stimuli, such as examples of abstract art or geometric patterns, which lack any meaning beyond that which an observer might idiosyncratically attach to them. Both types of stimulus, meaningful and meaningless, have been employed in recognition memory studies. In order best to replicate those studies, which used meaningful visual stimuli, it is necessary to have comparable auditory stimuli in the form of environmental sounds. This pilot study sought to explore the development of environmental sounds in preparation for their potential use in associative recognition memory experiments.

The second pilot study explored variation in item recognition performance for a range of different kinds of stimulus. These stimulus types included a variety of visual stimuli as well as auditory stimuli (environmental sounds and spoken words). While a variety of stimulus types have been employed in item (and associative) recognition tasks, no study has directly compared item recognition memory for several stimulus classes simultaneously. Associative recognition, although ultimately testing memory for the association between, or co-occurrence of, two items must include memory for the component items themselves. It is unknown to what degree variations in the ease of item memory for different types of stimulus might affect memory for pairs comprising those items. An important first step in exploring this issue is to establish if and where there are significant differences in item recognition performance for different kinds of stimulus. Pilot study two employed a continuous item recognition procedure to investigate this variation.

The third pilot study examined the relative levels of associative recognition for auditory and visual associative recognition memory. The auditory stimuli used three combinations of auditory stimuli: pairs of ‘meaningful’ or ‘environmental’ sounds, associations between
‘meaningless’ or random noises (produced for this pilot study), and associations between ‘meaningful’ and ‘meaningless’ sounds. The auditory associations, therefore, involved two within-domain and one between-domain kind of association. The visual association was a within-domain association using paired animal pictures. The study aimed to get an initial impression of how well pairs of auditory stimuli are remembered and to provide a comparison of this level of performance with memory levels in a conventional visual associative task. It aimed to identify any potential difficulties there might be in making such comparisons between visual and auditory stimuli. Owing to these goals, familiarity was not measured, and instead a standard yes/no recognition paradigm was used.

Part 2.

In the fourth study, which represents a coherent and elaborate experimental paradigm, both associative recognition and associative familiarity were measured for a variety of within-domain and between-domain visual associations. To the extent that these associations were between-domain, the initial version of the Domain Dichotomy theory (Mayes et al., 2007) would predict that within-domain associations should be supported by more associative familiarity (either in an absolute sense, or as a proportion of associative recognition) than will be the case for between-domain associations. This prediction is subject to only two provisos. First, the fundamental basis of the theory concerns where different kinds of information converge in the medial temporal lobe, so the within- versus between-domain part of the theory may need to be revised even if this fundamental basis is well supported. This will, of course, require testing with neuroscientific methods, including fMRI and lesion studies. Secondly, if unitisation occurs, then the theory postulates that its components must have been mnemonically processed either in the perirhinal cortex, the parahippocampal cortex, or both, and associative recognition will be supported well by familiarity. It is agreed that unitisation need not occur in an all-or-none
fashion, but might develop by degrees or in stages, but subjective rating scales have never been used and there are no objective criteria that have been validated against such subjective rating scales (Yonelinas, Aly, Wang, & Koen, 2010). At present, therefore, we can learn how well (after rapid learning) within-domain and between-domain associations are supported by familiarity, but not how much this depends on the creation of intra-item (or intra-component) as opposed to inter-item associations, although the subjective impression given by participants is that they experience a feeling that separate items have appeared together before.


Pilot Study 1. Auditory Stimulus Selection

Introduction

Auditory stimuli offer the clearest examples of stimuli that must differ from any given visual stimulus, based merely upon the different sensory cortices involved in their initial processing. Moreover, as the origin of an auditory stimulus signal is located elsewhere in the neocortex from visual signals, its locus of entry to the medial temporal lobe may be different, although it is known that both modalities receive some processing from the perirhinal cortex. It is unclear whether the location of declarative memory processing for auditory stimuli differs from that of visual stimuli. It remains specifically difficult to answer as auditory stimuli must be investigated that differ from each other in the same way that visual stimuli do. In other words, just as visual stimuli can be neatly grouped into recognisable categories so, too, must this be possible for auditory stimuli.
Although auditory stimuli must be categorised depending upon their content (for instance, the presence or absence of semantic content, or whether the sound is symbolic as it is in the case of a word), it is unclear that distinguishing between different types of auditory stimuli is as easy within the context of a memory experiment as it is for visual stimuli. In the following pilot studies, three categories of auditory stimuli were used in order to determine whether they would be suitable for subsequent associative recognition memory experiments. The categories of auditory stimuli included ‘spoken words’, ‘environmental sounds’ (containing semantic information) and ‘random noises’ (devoid of semantic information).

This pilot study sought to prepare environmental sounds for use in subsequent associative memory experiments. Environmental sounds have previously been defined as containing semantic information. Consequently, it is necessary that any given stimulus must be identified by participants. Multiple potential environmental sounds were presented to participants who, initially, were asked to indicate whether or not they thought they recognised the sound and, subsequently, to inform the experimenter what they thought was making the sound.

**Method**

**Participants**

Fourteen (eight female) University of Manchester Students took part in the experiment. The mean age of the participants was 20.21 (SD 1.67). All participants were native English speakers. Two were left handed. The study was approved by the School of Psychological Sciences Research Ethics Committee of the University of Manchester and informed consent was
obtained from the participants. The participants received course credits for participation as part of their undergraduate degree in Psychology.

**Stimuli**

Stimuli comprised 85 recordings of environmental sounds, including noises such as ‘a car being started’ and ‘a clapping audience’. These were taken from an existing research database at the University of Manchester. All the sound files used were Wav files with a bit rate of 88.2Kbps: they were sampled at 11.025 KHz with a bit depth of 8 and were presented in mono. These standards were employed to ensure compatibility with E-Prime (version 1.1.4.1) presentation software (www.pstnet.com). Each sound varied in length from 1000ms to 5000ms and was presented once. For instance, the sound of ‘a clapping audience’ lasted the whole 5000ms while the sound of ‘a car door closing’ lasted for 533ms. Owing to the different lengths of the audio files some sounds were presented for a longer period than others. Forty one stimuli were presented for the full 5000ms while forty four were presented for varying amounts of time with an average presentation length of 1924ms (SD 1476ms). The total mean presentation time for all of the items including those presented for the maximum 5000ms was 3408ms (SD 1872ms).

**Procedure**

The experiment was presented using E-Prime presentation software. The participants’ ability to recognise the stimuli was assessed in two phases. During the first phase the stimuli were randomly presented. The presentation time for each stimulus was 5000ms, irrespective of the duration of the given sound. After a given stimulus was presented, participants indicated whether or not they ‘thought they had recognised the sound or what was making the sound’, using a keyboard. In the second phase each sound was presented a second time in a pre-selected
order. Each time a sound was presented participants were instructed to inform the experimenter whether or not they thought they recognised the sound and, if they were able to do so, to state what they thought the noise represented. Once the experimenter had recorded the response the participant continued to the next stimulus.

Results

First Phase

Of the 85 environmental sounds, each participant indicated they recognised an average of 57 items (SD 7.65, Range 48-76) although which items identified varied between participants. 18 items were identified by all 14 participants while a further 8 items were recognised by 13 participants and 9 items were recognised by 12 participants. Over 30 items were identified by 80 percent of participants. Every item was identified by a participant at least once (see Figure 3).
Figure 3. Cumulative frequency chart outlining environmental sounds recognised.

A cumulative frequency chart showing the number of items recognised by varying proportions of participants. As the chart moves to the right more and more items are recognised by a smaller proportion of the participants. On the left hand side of the chart, 18 sounds were recognised by 100% of the participants while 30 items were recognised by over 86% of participants.

Second Phase

Of the 85 environmental sounds presented, the source of the sounds was identified correctly on average for 37 items (SD 6.02). Across the participants, the lowest number of items identified was 18, while the greatest number was 47.

A paired samples t-test was conducted in order to compare the number of sounds the participants thought they could recognise (results from phase one) and the number of sounds they actually recognised (results from phase two). The number of sounds that they thought they
could recognise was significantly greater than the number that they could correctly recognise \( (T_{[13]} = 7.779, p<0.001) \).

A Pearson’s \( r \) correlation was conducted in order to test whether or not there was a linear relationship between the number of items people thought that they were able to recognise (phase one) and the number of items that they actually recognised (phase two). There was no significant correlation between the number they thought that they could recognise and the number that they actually recognised \( (r=0.053, n=14, p=0.858) \).

**Discussion of Auditory Stimulus preparation**

Auditory stimuli have been used rarely in memory experiments. In order to explore fully the distinct effects that auditory stimuli may cause, it is necessary to have three distinct types of stimulus. In this pilot study ‘environmental sounds’ were prepared while ‘spoken words’ and ‘random noises’ were prepared in Pilot Studies 2 and 3 respectively. The spoken words were spoken versions of the written words used as visual stimuli (see Pilot Study 2 ), selected according to the same criteria as the written words and the random noises were distorted versions of the least recognised environmental sounds (see Pilot Study 3). In order to elicit semantic activations in the neocortex an environmental sound must be recognisable. To ascertain which auditory stimuli were most recognisable and, therefore, appropriate for use in experiments of this kind, recordings of environmental sounds were presented to participants who were asked to indicate which sounds they thought they recognised, or of which they could visualise the source. Only a relatively small proportion of the sounds were recognised by all the participants but a larger number were recognised by the majority.
In order to run a memory experiment using auditory stimuli with the same distinction between categories of stimulus as a visual study where abstract images are contrasted with real objects (i.e. sounds with semantic content in one category and sounds without semantic content in another) it would be essential to use sounds which can be easily and consistently identified as either having, or not having, semantic content. Around 30 such stimuli should be needed. This study highlights the difficulty that participants face in identifying the sources, or even likely sources, of common environmental noises. Nonetheless, based on recognition rates reported for the presented stimuli, 30 approached this standard. Over half of those 30 were recognised 100% of the time and the other 15 were still identified by over 85% of the participants. These numbers relate to First Phase of the pilot study using the self-reported ‘recognition’ of the stimuli. As is outlined below, most participants were broadly accurate in their identification of the stimuli even if specifically they were incorrect. So long as participants were able to recognise the sounds, as opposed to being unable to recognise them, they will have processed the stimulus with semantic information supporting the sounds inclusion in the environmental sounds category. While these numbers (not all of the stimuli were recognised by all of the participants) would be insufficient for a principal study of auditory recognition memory, they are sufficient for use in further exploratory studies relating to the use of auditory stimuli (see further pilot studies in this chapter).

In addition to the difficulties in preparing stimuli that were considered recognised (sufficient for semantic content to be present), the second phases of the study highlights the difficulty people have in actually identifying environmental noises. Just because people thought they were recognising the items, did not mean that they were correctly identifying the source of the noise. The accuracy of the participants’ recognition of the sounds was tested in the second phase of the experiment. The results showed that, even though many of the participants thought that they could recognise the noise, it was relatively rare for them to do so accurately. Absolute
performance accuracy was low in almost all participants. It was also the case that the number of sounds that participants thought they were able to recognise was not a good indicator of the number actually recognised at test. Nonetheless, a visual inspection of the responses given indicated that some responses made were highly plausible, or only slightly different from the noise’s actual origin. For instance, one noise represented the sound of a motorbike engine, and many ascribed it to a car, truck, or other motor vehicle. This is a subtle difference and, while these participants were not technically right, there can be little doubt that, for many, their recognition was in the same general area as the actual source of the sound. This explains the finding of absence of a correlation between correctly identified items and items thought to be correctly identified by participants. A further interesting result was that some sounds elicited consistent, albeit incorrect, recognition responses among the majority of participants. An example of this was the sound of ‘a fax transmission’ which was mistakenly identified as the sound of ‘a modem logging on’. Nonetheless, these findings are not necessarily as important as they might seem. As long as the participants recognise the auditory stimuli, neocortical activity should be elicited, and it is likely that, even if participants do not recognise the sound correctly (or even consistently), the imagined sources will be very similar. What matters most is whether a sound is consistently given a semantic interpretation by participants, not whether he is correct. Therefore, although imperfect those stimuli which were recognised, irrespective of whether that recognition was correct, will be used in Pilot Studies 2 and 3.

Despite the relatively infrequent use of auditory stimuli in memory experiments, there are both ecological and neuropsychological reasons for thinking that they will be processed differently from visual stimuli. This has greater importance in light of the Domain Dichotomy theory’s suggestion that different kinds of stimulus will be processed in distinct ways. These varying kinds of stimulus should recruit different regions of the medial temporal lobe, contributing to variations in the kinds of associations that can be formed between items. The
production of three specific kinds of auditory stimuli allows them to be matched with comparable visual stimuli.

Although it was decided not to employ auditory stimuli in the associative recognition memory experiment (see Part 2) certain recommendations can be made regarding how best to prepare environmental sound stimuli in the future. It was apparent from the results of this pilot study that participants struggled to identify either correctly, or incorrectly, the environmental noises. It would be important to produce as many distinct sounds as possible for participants to identify. A good source of potential sounds may well be animal sounds. Most animals make distinctive noises with clearly linked semantic information. This would also facilitate a clear comparison with images of animals. A general point would be to maximise the quality of the audio files and method of presentation by using a high quality workflow from recording the sounds, through editing and finally at presentation by employing professional grade audio equipment software and practices. The version of E-Prime presentation software (www.pstnet.com) employed in this study (version 1.1.4.1) limited the type and quality of audio file used. Newer versions, or alternative methods of presentation, may allow higher quality files, which may be easier to identify. These techniques should be used in the future when preparing audio files for use in recognition memory experiments.

Pilot Study 2. Recognition Memory for different kinds of stimuli

Introduction

Associative recognition memory is defined as a memory for the association between two or more items. However, for that association to occur it is necessary for there to be items to be associated. The Domain Dichotomy theory makes specific predictions about how, and when,
familiarity processes may contribute to associative recognition memory, without making substantially novel predictions concerning how items themselves are remembered. It does emphasise that even items comprise multiple component parts and it discusses the difficulties of measuring unitisation. Nonetheless, given that the majority of items are considered to be items without confusion, except under exceptional circumstances, it is typically unnecessary to discuss item memory within the context of associative memory.

One area in which item memory may play a significant role in affecting associative memory is in the varying difficulty of remembering individual components of an association. Variation in the difficulty of remembering different items is not a new concept, as demonstrated by the large amount of literature exploring the 'picture superiority effect' (Weldon, 1989). This effect is that images of items are better remembered than the words which represent them. Despite this, no theory specifically makes predictions concerning how the difficulty of remembering any particular stimulus, or stimulus category, will affect memory for associations including that item. This is because, while some stimuli might be easier or harder to remember, it is assumed that given appropriate study conditions (providing sufficient time or exposure for efficient encoding) any such stimulus can be remembered effectively. Furthermore, remembering any given item stimulus, irrespective of difficulty, is assumed to be dependent on broadly the same kinds of processing. This same reasoning cannot be applied to associative recognition memory. It is unknown how studying pairs comprising very easily remembered stimuli and, relatively more difficult to remember stimuli, might affect the resultant associative memory performance. This also applies to examples wherein difficult items are paired with difficult items or easily learnt items with easily learnt items. It is possible that difficult items (when paired together) multiply in difficulty, resulting in very low associative memory performance. Equally, it is possible that associative memory performance might be higher than expected because it is
easier to remember difficult items when they are associated with another item, regardless of how difficult those component items are to remember individually.

Compounding this outstanding issue of how item learning difficulty might interact with associative memory, variations in item memory have not been systematically explored. Despite acknowledging that differences can exist, the lack of a systematic analysis concerning the differences of the degree to which memory performance can vary, depending upon which stimulus type is being remembered, represents a significant flaw in planning any associative memory test. It may be the case that substantial differences in memory performance are present across different types of stimulus, or that there are relatively small differences. If there are large differences it might be necessary to encode the weaker stimuli with additional study time in order to match performance whereas, if memory performance is broadly similar this would not be necessary. In any test of the Domain Dichotomy theory it will be necessary to compare directly the associative memory performances for different kinds of pairs. For those comparisons to be fair it is necessary to rule out the potential influence of variation in item memory performance. This pilot study is vital to establish whether or not further manipulations are required to compensate for significant variations in item memory performance.

This study sought to assess memory performance for seven different stimulus types, using a continuous recognition paradigm. The use of a continuous recognition paradigm differs from standard tests of recognition memory. However, it has a number of advantages including that the duration between study and test can be manipulated whilst, simultaneously, more stimuli can be tested within a given time window than would be possible in a conventional test. The use of a random spread of types of stimulus between the first and second presentation of items avoids proactive or retroactive interference such as might be generated by studying another type of stimulus in the space between study and test of the target stimuli. Finally, it provides a more
natural test of memory for the tested items, drawing upon a diverse range of memory representations across time, than is the case with typical block designs. The comparatively novel paradigm, especially with the given variety of stimulus types, potentially lends itself well to further use in exploring the Domain Dichotomy theory, but requires testing in order to assess its practicability.

The following pilot study’s aims were to measure differences in recognition memory performance across seven varied stimulus categories within a continuous recognition paradigm, exploring the possibilities for future tests and identifying potential weaknesses that might need to be addressed.

Method

Participants

Eleven (six Female) University of Manchester Students took part in the experiment. The mean age of the participants was 23.9 (SD 2.98). All participants were native English speakers. One was left handed. The study was approved by the School of Psychological Sciences Research Ethics Committee of the University of Manchester and informed consent was obtained from the participants. The participants received course credits for participation as part of their undergraduate degree in Psychology.
Stimuli

Seven categories of stimulus were used. Each category comprised 30 items. These were as follows:

Faces;
Visual Scenes;
Pictures of Animals;
Pictures of Tools;
Written Words;
Spoken Words;
Environmental Sounds

These stimulus classes were chosen to represent intuitively different kinds of information. A clear difference is immediately obvious as some of the stimuli were presented visually whilst others were presented auditorily. This difference in modality should result in distinct patterns of activation throughout the brain, and specifically the medial temporal lobe, owing to different early processing cortices and their subsequent projections into the medial temporal lobe. Within the two domains of auditory and visual stimuli, different kinds of stimulus were chosen to represent different kinds of information. Traditional theories of semantic knowledge separate categories of stimuli into categories, such as animals and tools, based on evidence from such sources as semantic dementia (Caramazza & Mahon, 2003). Whether the differences in semantic content relate to specific areas of the brain or to varying degrees of overlap in the neural representations of those semantic concepts, semantic similarity is likely to be a significant factor in defining whether two stimulus classes are processed in similar ways. In addition to the semantic similarity, the degree to which stimuli are perceptually similar may contribute to overlap in their processing within the medial temporal lobes. Thus, each category
of stimulus was chosen because it differed substantially in its semantic and perceptual content from the others. Within the auditory condition, it is more challenging to select stimuli that differ both in semantic and perceptual qualities but ‘spoken words’ differ perceptually from ‘environmental’ sounds'.

Faces

Faces have often been used in studies of recognition memory. Within the ‘face’ category, there were 15 male and 15 female faces which were cropped to remove background, decorations and clothing; however, hair remained. No clearly distinguishing features (e.g. jewellery, tattoos) were present; nonetheless, the faces were all reasonably distinctive. The removal of background, decorations and clothing was effected in order to focus the participants’ processing of the image as a face (as opposed to a scene) and distinctive faces were chosen in order to improve performance and to facilitate the use of familiarity in recognition. Previous findings have suggested that the use of highly cropped faces (including such features as hair) limits the ability of participants to use familiarity to recognise faces (Curran & Hancock, 2007). See Figure 4 for examples.

![Faces](image)

**Figure 4.** Examples of face stimuli.
Visual Scenes

The ‘visual scenes’ category included 15 outdoor and 15 indoor scenes. The outdoor scenes included compositions such as a rural landscapes, but also more urban settings, including some images with people (although they were not the focus of the scene). The indoor scenes included images such as empty rooms in a house (e.g. a kitchen) and large meeting rooms with people although, once again, the images were selected so as to ensure that the people were not the focus of the scene. See Figure 5 for examples.

Figure 5. Examples of visual scene stimuli.
Pics of Animals

For the ‘animals’ category 30 animals were chosen, ranging from common, every day examples (a duck) to the more exotic (a polar bear). The images were colour artistic representations of the creatures drawn to imitate life but they lacked texture and shading beyond boundary lines. See Figure 6 for examples.

Figure 6. Examples of animal stimuli.
The 30 pictures of tools were stylistically similar to those of animals. Items in the category included clear examples of tools (e.g. a rake) but also some items that fell within the parameters (an inanimate object used to accomplish a task) but that are less often thought of as ‘tools’ (e.g. a door handle). See Figure 7 for examples. Whilst many of the items were clearly different from one another, there were greater similarities between some of the items (e.g. a screw and a nail) than existed between the items in the animal category.

Figure 7. Examples of tool stimuli.
Written Words

The 30 written words used were chosen to conform to general standards. These included being concrete nouns, having high levels of imageability, concreteness and familiarity, but having a low frequency score in the Thorndike-Lorge frequency database. These attributes were assessed using the MRC Psycholinguistic Database. Those words chosen scored over 500 on the imageability, concreteness and familiarity scales, making them recognisable and easy to conceptualise. Simultaneously, they were selected to score less that 250 on the Thorndike-Lorge written frequency measure. This is a database of commonly written words dating from 1944 which rates their use per million words (Thorndike & Lorge, 1944). By establishing a low level of general usage, participants can easily focus on the occurrence of the word in the memory experiment as distinct from exposure to it in everyday life. While data on all of the scales were not available for every word, those selected were chosen to conform as closely as was possible. They were presented in size 18 Arial font. See Figure 8 for examples.
Figure 8. An example of a written word stimulus.

Spoken Words

In order to maintain the greatest possible similarity between ‘spoken words’ and ‘written words’ the 30 spoken words were selected according to the same criteria as the written words. They were recorded prior to the experiment by a male speaker who was instructed to emphasise each syllable of the word in an effort to maximise clarity.
The ‘environmental sounds’ were specifically selected in order to be recognisable so as to elicit semantic processing. These environmental sounds were selected from the 30 sounds most commonly recognised and produced in Pilot Study 1. Consequently, the caveats detailed in the discussion of that study stand. While over half of the stimuli were recognised 100% of the time and no stimulus was recognised by fewer than 85% of the participants, it is possible that some participants might not be able to recognise the source of the noise and, therefore, would deprive that stimulus of the semantic content which is necessary for its inclusion in the ‘environmental noise’, as opposed to ‘random sound’, category. In spite of this potential pitfall, the general compliance with the requirement of recognition indicates that it is reasonable to use these stimuli in further exploratory studies as long as any given results are interpreted with this fact in mind.

As stated above, 30 environmental sounds were presented. The length of the sounds varied. The sounds were played for five seconds. Longer sounds terminated at the end of those five seconds. For those sounds shorter than five seconds a 500ms period of silence was inserted after the sound’s termination, at which point the sound was repeated. This occurred until the five second period was complete.

**Procedure**

There were 30 stimuli in seven categories totalling 210 individual stimuli. Each stimulus was presented twice, resulting in 420 individual stimulus presentations. The order of the stimuli was picked randomly. Random selection meant that, at any point, any stimulus could be chosen. While this introduced an element of confound (it was possible for items to be repeated very
close together or far apart), it meant that performance could be assessed as a factor of how far apart the first and second presentations were.

Participants were tested on simple recognition, answering the question “has this stimulus been presented before?” After each stimulus’ presentation the participants were presented with a screen for 3000ms, asking them whether or not it had been presented before. This slide was included in order to accommodate participants listening to an entire sound stimulus, prior to needing to make a memory judgment. Participants responded by pressing either ‘y’ or ‘n’ on the keyboard for ‘yes’ or ‘no’ respectively. As soon as they had responded, a 500ms fixation cross was presented and the next stimulus was then displayed. If they did not respond within 3000ms the fixation cross and next stimulus were presented. This continued until all the stimuli had been presented twice.

**Results**

Memory performance was calculated as hit rate minus false alarm rate for each of the categories. Hits were calculated as responding “yes” (a given stimulus was presented before) for the second presentation of a stimulus. A false alarm was indicated when responding “yes” on the first presentation of the stimulus.

The mean total recognition memory performance was 0.74. Memory performance was also analysed comparing scores for the individual types of stimulus. Memory performance was lowest for ‘spoken words’, with a score of 0.63, while performance was highest for ‘animals’, with a score of 0.81 (see Table 1).
A repeated measures ANOVA was conducted in order to compare memory performance (Hit rates minus false alarm rates) across the different types of stimulus. There was a significant main effect of stimulus kind ($F_{(6,60)} = 3.905$, $p<0.05$). LSD post hoc analysis indicated that recognition of ‘spoken words’ was significantly lower than for ‘animals’ and ‘scenes’, whilst recognition for ‘faces’ was significantly lower than for ‘animals’ (all $p<0.05$) (see Figure 9).

**Table 1.** Mean levels and standard deviations of performance for each category of stimulus.

<table>
<thead>
<tr>
<th></th>
<th>Environmental Sounds</th>
<th>Spoken Words</th>
<th>Faces</th>
<th>Tools</th>
<th>Scenes</th>
<th>Written Words</th>
<th>Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hits-FA</strong></td>
<td>0.73 (0.09)</td>
<td>0.63 (0.22)</td>
<td>(0.09)</td>
<td>(0.13)</td>
<td>(0.13)</td>
<td>0.72</td>
<td>0.81</td>
</tr>
<tr>
<td><strong>Hits</strong></td>
<td>0.83 (0.09)</td>
<td>0.72 (0.13)</td>
<td>(0.10)</td>
<td>(0.11)</td>
<td>(0.11)</td>
<td>0.74</td>
<td>0.82</td>
</tr>
<tr>
<td><strong>FA</strong></td>
<td>0.10 (0.05)</td>
<td>0.09 (0.12)</td>
<td>(0.05)</td>
<td>(0.04)</td>
<td>(0.02)</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Figure 9. Performance for each of the seven types of stimulus and the significant differences between certain groups as shown by the repeated measures ANOVA.

A factorial repeated-measures ANOVA was conducted in order to compare Hits rates and False-Alarm rates across the different types of stimulus. There was a significant main effect of Hit rates and False Alarm rates ($F_{(1,100)} = 835.213, p < 0.001$). There was a significant main effect of Stimulus type ($F_{(6,60)} = 7.015, p < 0.001$). There was a significant interaction between Hit rates and False Alarm rates across the different kinds of stimulus ($F_{(6,60)} = 3.856, p < 0.01$). The significant interaction demonstrates that memory performance (hit rate minus false alarm rate) varied with some stimulus categories being more strongly affected by false alarms than others. This is illustrated by the finding that when memory performance is calculated as hit rate minus false alarm rate Tools and Scenes are recognised at the same level (0.80). However, this number results from higher hit rates and false alarm rates in the case of Tools (hit rate 0.88 false alarm rate 0.08) compared with Scenes (hit rate 0.81 false alarm rate 0.02). An alternative example is
that of the Face and Animal stimulus categories which have similar hit rates (0.78 and 0.82 respectively) but very different hit rate minus false alarm rates (0.70 and 0.81) as a result of varying false alarm rates (0.08 and 0.01).

The results (hit rates minus false alarm rates) for all of the individual categories fall within a reasonable range for recognition test performance (above .5 and below .9) using the hit rate minus false alarm rate calculation. This demonstrates that performance was better than chance and unlikely to be affected by ceiling effects. Nonetheless, as the focus of this study aimed to assess item recognition memory performance accurately and to compare across stimulus types, it is important that memory performance in those categories which had high levels of performance was not prevented from being higher by a ceiling effect. In order to test for this a series of one sample t-tests were conducted in order to compare memory performance for the three categories with a perfect score of 1.

Scenes \(T_{(10)} = -5.513, p<0.001\).

Tools \(T_{(10)} = -4.979, p<0.001\).

Animals \(T_{(10)} = -7.247, p<0.001\).

In order to assess the effects of distance on memory (hits) between the first and second presentations (measured by the number of intervening stimuli) the entirety of each participant’s responses were grouped by lag increasing in increments of 50. Their hit rate was then calculated as a proportion of the total number of items (hits plus misses) presented after that given lag (see Table 2).

Taking the mean stimulus lag for each of the 50 item brackets (25, 75, …) a significant negative correlation was found between successful identification and increased lag times (r=...
-0.891, n=9, P<0.001). This correlation shows a strong linear trend for hit rates to decline as the lag between first and second presentation increases.
The proportion of hits by stimulus lag (distance).

<table>
<thead>
<tr>
<th>Stimulus Lag</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>0.98</td>
<td>0.02</td>
</tr>
<tr>
<td>51-100</td>
<td>0.90</td>
<td>0.05</td>
</tr>
<tr>
<td>101-150</td>
<td>0.85</td>
<td>0.05</td>
</tr>
<tr>
<td>151-200</td>
<td>0.77</td>
<td>0.12</td>
</tr>
<tr>
<td>201-250</td>
<td>0.77</td>
<td>0.10</td>
</tr>
<tr>
<td>251-300</td>
<td>0.74</td>
<td>0.16</td>
</tr>
<tr>
<td>301-350</td>
<td>0.65</td>
<td>0.12</td>
</tr>
<tr>
<td>351-400</td>
<td>0.61</td>
<td>0.40</td>
</tr>
<tr>
<td>401-450</td>
<td>0.20</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Table 2. The proportion of hits by stimulus lag (distance).

Discussion

This study sought to test the degree to which standard recognition memory performance differs for a variety of different types of stimulus. An unconventional experimental design was employed making it possible simultaneously to test item memory performance within a continuous recognition paradigm. Memory performance was substantial for all stimulus categories, while avoiding ceiling effects.

Significant differences were found in average memory performance for the different classes of stimulus. However, while these differences are statistically significant they do not represent major differences. The mean recognition memory performance of the worst stimulus category still amounted to 75 percent of the performance of the best remembered category. This finding supports the idea that variations in item memory performance should not constitute a
serious confounding factor in future tests of associative memory, if study conditions are matched. As noted above, the environmental sounds were imperfectly selected so that it was highly likely that some of the participants would not have identified some of the noises. If this were the case, then the environmental sound category will have included some stimuli which should have been classed as random noises. It cannot be concluded from these results whether memory performance for this group would have increased or decreased had all of the environmental sounds been correctly identified. However, as the environmental sounds fell in the middle of the range of memory performances (memory performance for environmental sounds was not significantly different from any other categories of stimulus), and the number of sounds not identified by any given participant would have been relatively small, it can be concluded that it would not have made a dramatic difference radically altering memory performance for that category in this study. Should dramatic variations in associative memory performance be found for certain pairs of stimuli, it should be possible to refer to these findings in order to clarify whether a pattern of poor associative recognition memory can be related to the small, but significant, differences in item recognition memory performance for certain categories of information.

Concerning whether a continuous recognition procedure represents a potential method for future recognition memory studies, a key finding was made and other factors became apparent during the course of the study. Recognition memory performance differed depending on the length of time between the first and second presentation. Memory for those items repeated within 50 stimulus presentations was generally very high, while those items presented with more than 150 intervening items had markedly lower levels of recognition. This suggests that, for a conventional item recognition study, stimuli should be repeated after a gap of between 50 and 150 other stimuli. Should further testing manipulation variations be considered, such as the use of a familiarity only paradigm or shorter stimulus presentation times, particularly if these
A final consideration is that, in any continuous recognition paradigm, there is a preponderance of new items at the beginning of the study and old items at the end. Such was the case in this study and the perception of participants that most stimuli are likely to be new or old at certain points in the study may influence their judgements and/or shift their criterion for making those judgements. This elementary finding represents a fundamental problem unique to the methodology of continuous recognition. In order to avoid this, ‘dummy stimuli’ (i.e., stimuli included, but not analysed for memory performance, and indistinguishable to the participant), must be included at the beginning and end of the experimental run. In the early stages of the experiment, these dummy stimuli must be presented and repeated with very few inter-presentation stimuli while, at the end, further dummy stimuli must be presented for the first time without repetition in order to provide new items to be correctly rejected amongst the multitude of old items.

In conclusion, this study sought to establish, successfully, the degree to which item memory varies for different types of stimuli within a continuous recognition paradigm. While memory performance differed significantly between some (but not all) categories of stimulus, no difference was greater than 25 percent. The study also assessed elements of the continuous recognition paradigm that must be considered in order to optimise findings, including spacing of repetitions and the use of dummy stimuli.
Pilot Study 3: Auditory associative recognition

Introduction

A strong method of testing the Domain Dichotomy theory includes testing recognition memory for pairs which are more or less similar to each other, in both the visual and auditory domains. Previous studies (see above) have prepared auditory stimuli for use, overcoming some of their inherent difficulties. In addition, it has been shown that item recognition memory performance, for at least some auditory stimuli, is not significantly different from that of the majority of visual stimuli in a continuous recognition paradigm.

A question remains, however, as to how auditory stimuli might be incorporated into an associative recognition memory experiment. The presentation of auditory stimuli in the previous continuous recognition study did not require a different method of presentation, as each sound was presented in a similar manner to that of a visual stimulus. Presentation duration was standardised across the types of stimuli with any given stimulus either presented on the screen, or played through speakers. Participants asked themselves whether or not they thought they had previously encountered the stimulus and responded appropriately during the presentation of that stimulus. Associative memory experiments, in contrast, have specific demands that need to be met and that differ from those of an item memory experiment. In associative memory experiments participants must be exposed to multiple stimuli in a way that allows them to perceive any two stimuli as being paired together and, therefore, as distinct from the other pairs of stimuli that were not studied together, although they were studied.

In conventional associative memory experiments using visual stimuli the pairing of items is achieved by presenting both, simultaneously, on the screen. The images, be they words,
objects, scenes, or any combination of possible visual stimuli, are naturally seen to go together, whilst those stimuli presented, whether before or after that pair, are judged to represent a separate set of items to be associated. This simultaneous presentation of items is possible because the visual system is able to focus quickly on each item in turn, giving the effect of simultaneous perception. In some cases (depending upon the exact method of presentation, including the size of the stimuli, distance between the stimuli, and method of encoding, e.g., the instruction to imagine a given object in a stated colour) it may even be possible to process both in a truly simultaneous fashion. Irrespective of whether perception is truly simultaneous, or simply achieved by fast switching between the component items, it is possible to process the two images and encode them into memory as a pair, as demonstrated by later recognition memory performance in countless experiments.

This method of presentation is, at best, complicated by the fundamentally temporal nature of auditory stimuli. Any auditory stimulus is defined, not only by the component tones or sounds, but by the specific unfolding of those elements through time. It is necessary, therefore, for participants to focus on each stimulus for its entire duration to be able encode it. This is the case whether they need to hear the sound fully in order to recognise it (in the case of environmental sounds), or to encode the random pattern of noise so as to differentiate it from other random sounds.

There is a body of evidence that has investigated the ability to process two auditory stimuli simultaneously. At least two sets of auditory stimuli are presented via a set of headphones, with each stimulus presented to one or both ears, simulating a frontal stimulus. These studies often include spoken sentences and seek to explore the ‘cocktail party effect’. Stifelman (1994) conducted such an experiment and found that participants were able to detect 63.1% of targets in both the primary and secondary channels; however, when participants had to
attend to three separate audio tracks, listening comprehension scores and target identification dropped significantly. This suggests that at least two auditory stimuli, potentially, could be presented simultaneously and still be encoded into memory by participants. The methodology of Stifelman’s experiment (and the other experiments in this literature) are, nonetheless, very different from those that would be found in a given recognition memory experiment. For instance, the auditory stimuli presented were passages of 180 words and memory itself was not measured. It is also emphasised that during this task, and other such tasks, there is always one audio stream which forms the primary focus and it is not possible to attend to each equally. It might be interesting to explore the effects of simultaneous presentation of auditory stimuli on memory but, even assuming that it is possible for participants to show above chance associative recognition after filled delays, the increased difficulty of attending simultaneously to two separate, and distinct, audio streams is likely to substantially impair associative memory performance.

The most natural alternative to simultaneous presentation of auditory stimuli is sequential presentation. This, unfortunately, is not without its own complications. The most obvious is that such sequential pairings would necessitate either a different procedure for the entire experimental paradigm (with visual stimuli also being presented sequentially), or some other sort of matching procedure where overall memory performance was matched. The other confound created by the use of sequential presentation is an inevitable reduction of clarity concerning which two sounds represent a given pair. For instance, if sounds A and B are played sequentially followed by C and D, it may be unclear in the mind of the participant that those are the actual pairings, as opposed to a pair consisting of sounds B and C. Finally, such sequential presentation might well negate the ‘direct encoding’ that is proposed to be required for the formation of familiarity for associations (Mayes, et al., 2007).
Despite the difficulties outlined above, the potential benefits of testing the Domain Dichotomy theory using auditory stimuli suggest that assessing participants’ ability to encode pairs of sounds in an associative memory task is an obvious step. The following experiment sought to test the viability of using auditory stimuli in associative recognition memory tests (as might be used to test the Domain Dichotomy theory), using the 30 ‘environmental’ sounds prepared in Experiment 1, along with 30 ‘random noises’ produced by digitally altering the 30 least recognised ‘environmental’ sounds (see methods). The absolute level of performance in the auditory associative task (assuming the absence of floor effects) alone may be insufficient to conclude whether or not the use of auditory stimuli is feasible in testing the Domain Dichotomy theory. Any test of the Domain Dichotomy theory will (most likely) also include pairs of visual stimuli and it needs to be established that memory performance is roughly similar for pairs of visual stimuli and pairs of auditory stimuli. If it is found not to be the case, this information can be used to explore potential modifications to match performance and consider the implications of doing so. In order to provide such a comparison, participants completed a standard visual yes/no associative recognition task in parallel with the auditory task.

**Methods**

**Participants**

Eleven (six female) University of Manchester students took part in the experiment. The mean age of the participants was 25.09 (SD 3.3). All participants were native English speakers. All participants were right handed. The study was approved by the School of Psychological Sciences Research Ethics Committee of the University of Manchester and informed consent was obtained from the participants. The participants received course credits for participation as part of their undergraduate degree in Psychology.
Stimuli

60 sound stimuli were used to form 30 pairs of stimuli. Of these 60, 30 were environmental sounds selected in study 1 as being most commonly recognised and were the same as those used in study 2. As with Pilot Study 2, the caveats about the recognisability of the environmental noises apply and are considered in the discussion. The other 30 sounds were modified versions of the least recognised stimuli from Pilot Study 1. Each sound was manipulated in Audacity (audacity.sourceforge.net) with modifications including, but not limited to, alterations in speed and tone, as well as including repetitions, echoes and reordering. The process took the least commonly recognised environmental sounds and produced 30 distinct, but artificial, noises without inherent semantic meaning.

In addition to the auditory stimuli, 60 animal stimuli were used in the visual associative task. These were drawn from the same pool as those in Pilot Study 2.

Procedure

Each participant completed a study phase with 30 pairs of sounds presented sequentially, followed by a test phase where 15 original pairs of sounds and 15 re-combinations were presented. The method of testing involved the presentation of original pairs and recombined pairs. The recombinations consisted of randomly rearranged original items. If pairs A-B, C-D, E-F and G-H were studied at test participants might be shown A-B, C-D, E-H and G-F. The recombined pairs were randomly generated by pairing second position items with first position items different from those with which they were originally paired. This method employed no novel items. This method ensures that the relative familiarity (or novelty) of any individual item
is insufficient to determine the type of pair (original or recombined). The order of original and recombined pairs was randomised at test and each item was only tested once either in a target or in a recombination pair. This resulted in participants being unable to judge the type of pair from any given pattern and either removed, or at least reduced, the possible cueing of responses to recombined pairs where one half of the constituent parts had already been presented. The study and test phases were separated by a two minute distractor task which consisted of counting backwards.

Participants were told to study the pairs because they would be required to identify whether or not those two sounds had been studied together at test. In both the study and test phases, participants were given a 2000ms visual cue indicating that a new pair of stimuli was about to be presented. Following this cue, the first sound in the pair was presented within a 3000ms window. The sound was played once within that window. After the first sound a visual cue indicating the imminent presentation of the second sound in the pair was displayed for 600ms. The second sound was then played once, within another 3000ms time window. Following the presentation of both sounds a 3000ms fixation cross (+) was presented. This procedure was employed so as to differentiate clearly between the specific pairs of stimuli. In the test phases a 3000ms visual cue was presented following the presentation of each pair which asked the participants to indicate whether or not they thought the previously heard pair of items had been presented together at study.

The pairs of sounds (30 environmental sounds and 30 random noises) were arranged in the following pairs: 10 environmental sounds were paired with 10 environmental sounds; 10 environmental sounds were paired with 10 random noises; and 10 random noises were paired with 10 random noises.
In addition to the auditory associative task, all but one participant completed a visual associative comparison task using pairs of animals. The order of completion of the auditory associative task and the visual associative task was counter balanced. The procedure was similar to that of the auditory task but used a more typical method of presentation (such as that used in the majority of visual associative tasks). Pairs of animals were presented simultaneously for 3000ms with 1000ms fixation points (+) separating each pair. Participants were told to study the pairs as they would be required to identify whether or not those two animals had been studied together at test. A two minute counting backwards distractor task separated the study and test phases of the experiment. Following the distractor task 30 more pairs were presented. Half of these were original pairs while the other half were recombinations of previously paired animals. Each pair was presented for 3000ms followed by presentation of a 3000ms response slide asking whether or not the previously studied pair of animals had been originally paired at study.

**Results**

Memory performance was calculated using hit rate minus false alarm rate in all cases. The mean recognition memory performance in the visual animal experiment (10 participants) was 0.67 (SD 0.18), while mean recognition memory performance in the main auditory experiment (11 participants) for all of the types of pairs was 0.10 (SD 0.17). The lower level of memory for the sound pairs was driven by a simultaneously lower hit rate (0.50 compared with 0.87) and a greater false alarm rate (0.39 compared with 0.20).
<table>
<thead>
<tr>
<th></th>
<th>Animal Pair Task</th>
<th></th>
<th>Sound Pair Task</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hits</td>
<td>FAs</td>
<td>Hits-FA</td>
<td>Hits</td>
</tr>
<tr>
<td>Mean</td>
<td>0.87</td>
<td>0.20</td>
<td>0.67</td>
<td>0.50</td>
</tr>
<tr>
<td>SD</td>
<td>0.27</td>
<td>0.17</td>
<td>0.18</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 3.

Recognition memory performance for the two types of associative memory including a breakdown of hit rates and false alarm rates.

A series of one sample t-tests was conducted on each of these sets of results so as to compare memory performance to zero. In the case of the visual associative ‘animal’ experiment, recognition memory performance was significantly different from zero ($T_{(9)} = 11.671$ $P<0.001$). The total recognition memory performance for the main auditory associative memory task was not significantly different from zero, although it did show a strong trend in this direction ($T_{(10)} = 2.015$ $P=0.072$). In order to test whether or not mean recognition memory performance was being adversely affected by any outlier participants, each participant’s total mean score was compared to the group’s mean score. No participant performed better or worse than two standard deviations from the mean.

A repeated measures t-test was conducted in order to compare the auditory associative and visual associative memory performances in the 10 participants who completed both tests. Memory performance was significantly higher in the visual associative memory task than in the auditory associative memory task ($T_{(9)} = -9.332$ $P<0.001$). There was no significant correlation between performance on the two types of associative test ($r = 0.439$, $n=10$, $P=0.205$).
Owing to the pairings of the auditory stimuli, (‘environmental’ sounds with ‘environmental’ sounds; ‘environmental’ sounds with ‘random noises’; and ‘random noises’ with ‘random noises’), it was possible to analyse separately the memory performance for each of these types of pairings. The associative recognition memory performances for the ‘environmental’ sounds paired with ‘environmental’ sounds, ‘environmental’ sounds paired with ‘random noises’, and ‘random noises’ paired with ‘random noises’ were 0.13 (SD 0.24), 0.18 (SD 0.32) and 0.00 (SD 0.31) respectively. A series of one sample t-tests was conducted in order to test whether each of these levels of performance was significantly different from zero. In each case they were not significantly different from zero: ‘environmental’ sounds with ‘environmental’ sounds ($T_{(10)} = 1.750$ $P=0.111$); ‘environmental’ sounds with ‘random noises’ ($T_{(10)} = 1.910$ $P=0.085$); ‘random noises’ with ‘random noises’ ($T_{(10)} = 0.000$ $P=1.000$).

As memory performance in the auditory associative task was not significantly different from zero at either the mean total or mean individual comparisons level, further analysis was not conducted.
### Mean Associative Memory Performance

**Mean (Hit Rate minus False Alarm Rate, SD)**

<table>
<thead>
<tr>
<th>Auditory</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Combined</td>
<td>0.10 (0.17)</td>
</tr>
<tr>
<td>Random &amp; Random</td>
<td>0.00 (0.31)</td>
</tr>
<tr>
<td>Environmental &amp; Random</td>
<td>0.18 (0.32)</td>
</tr>
<tr>
<td>Environmental &amp; Environmental</td>
<td>0.13 (0.24)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Visual</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Animals &amp; Animals</td>
<td>0.67 (0.18)</td>
</tr>
</tbody>
</table>

**Table 4.**

Mean memory performance ratings for the auditory and visual associative comparison task, including overall auditory associative performance and memory performance for each of the types of auditory association.

### Discussion

The pilot study under discussion sought to assess whether or not participants could study and retrieve associative memory for different kinds of auditory pairs, whilst controlling for their performance in a conventional visual associative task. It seems likely that, were the visual stimuli pairs presented sequentially, associative recognition would have been significantly worse than was found when the stimuli had were presented simultaneously, although this remains to be tested. Memory performance in the auditory associative recognition task was not significantly better than chance, while in the visual associative task participants performed well above chance.

Memory performance in the auditory associative task was not significantly different from zero. This resulted from a very high false alarm rate paired with a relatively low hit rate. This suggests that the participants’ memory for auditory associative pairs (as studied and tested in this paradigm) was not sufficient to distinguish between previously studied pairs of sounds and
subsequently recombined pairs. It is possible that, with greater numbers of participants, memory performance would have been significant even at this low level. Nonetheless, should that occur, memory performance would still have been very low. This level would have been little better than chance and far lower than that in the visual associative task (discussed below). With such a level of performance it would be difficult to explore differential contributions of familiarity and recollection to overall recognition memory. For instance, a modified remember/know paradigm such as the familiarity-only procedure would presumably lower memory performance even further (by excluding the contribution of recollection), unless familiarity was the sole memory process contributing to overall recognition performance. It is unlikely that it would be possible to find a significant level of associative recognition memory supported by familiarity, given the initially low level of overall recognition.

In contrast to the low level of performance on the auditory associative recognition task, participants were able to perform significantly above chance in the visual associative recognition task, with a relatively high mean average of performance. This suggests that the group of participants recruited for this test of auditory associative memory were typical in their ability to study pairs of items and to perform well on more typical tests of associative recognition memory. As described above, it is assumed that a relatively high level of standard yes/no associative recognition memory performance is desirable in order to explore the potential contribution of familiarity to overall memory. The level of performance shown here would be desirable, as neither floor nor ceiling effects were found. Within-domain pairs of animal stimuli were successfully employed in a behavioural test of the Domain Dichotomy theory as described in the experiment in Part 2 of this chapter.

A question remains, as was outlined in Pilot Study 2, of whether or not variations in item memory performance could have affected, perhaps even caused, the sharp difference in
associative recognition memory performance between the visual and auditory pairs. It is possible to examine the levels of item recognition for some of the stimulus types employed in this study because they (the animal and environmental sounds) were tested in Pilot Study 2 and, indirectly, in the fMRI experiment outlined in the next chapter (the random noises). At first glance the results seem to suggest it might be the case that the results are owing to variations in item recognition memory. The animal stimuli were the best remembered stimuli in Pilot Study 2 while the environmental sounds seemed to be less well remembered. However, although they appeared to be less well remembered than the animals they were not the worst remembered items. Importantly, given statistical analysis, there was no significant difference in item memory for the environmental sounds and the animal stimuli as measured in that study, suggesting that any difference is relatively minor.

Item memory for abstract sounds was not tested in Pilot Study 2 and, therefore, it is not possible to know for certain how item memory for those stimuli will have affected associative recognition memory performance for pairs including those sounds. Nonetheless, some indication might be drawn from examining measurements of item memory for abstract art stimuli (visual forms of abstract stimuli) as tested during the fMRI Experiment located in Chapter 3. These abstract art stimuli were some of the least recognised stimuli (only being recognised better than the category of faces) suggesting that perhaps abstract stimuli, in general, are challenging to remember. Nonetheless, memory performance was still well above chance, despite being produced within a familiarity only paradigm. This finding would not suggest an automatic floor effect for abstract stimuli. Finally, as demonstrated in the experiment described in Part 2 of this chapter, associative recognition memory (as measured using a standard yes/no recognition procedure) for a variety of types of pairs, both within- and between-domain and using many different types of stimulus, was consistently well above chance. These findings suggest that item differences in ease of remembering the component items of the pairs, while
potentially explaining some of the difference, cannot explain all of it and it can be concluded that
the participants exhibited a particular difficulty in remembering pairs of sound stimuli.

The good performance by the participants in the visual associative task should dispel the
argument that these participants were, by chance, simply unable to perform well in an associative
recognition memory experiment. However, with a limited number of participants it is,
unfortunately, the case that some participants may have performed very badly and, therefore, the
mean scores generated would not be representative. However, no participant was found to
perform markedly better or worse (falling beyond two standard deviations from the mean) than
the group as a whole. The auditory associative recognition task differed from the visual task in
that by completing the test participants were effectively studying and recognising three different
types of association (one between- and two within-domain association combinations of
environmental sounds and random noises). This was not so in the case of the animal pairings, as
all pairs were of the same type (within-domain animal pairs). It is not impossible that having to
try to learn and then remember different categories of information, whether for conscious or
unconscious reasons, might have had an adverse impact on memory performance. What seems
unlikely, however, is that the deficit would be so dramatic as to reduce memory performance to
chance. In addition, poor performance when remembering one type of pair might have adversely
affected the average when measured across all of the pairs. Acknowledging this minor risk, it
remains sensible, nevertheless, to examine memory performance for each of the different types
of association.

Within the auditory task there were three different types of auditory association which
were studied and tested. These included two sets of within-domain pairs and one set of between-
domain pairs. The two within-domain pairs represented pairs of auditory sounds with semantic
information in the ‘environmental sounds’ and without in the ‘random noises’. By acknowledging
the limited power that the reduced number of pairs provides, it is possible to explore potential memory performance in each of these different categories. It might have been the case that at least one of these categories of stimulus pairs provided strong memory performance, whereas the other two were sufficiently low that overall memory performance was still not significantly different from zero, or that one of these categories was sufficiently poor that it reduced the other two which, though weak, were above chance. This did not occur, as memory performance for each category of pairs was still not, individually, significantly different from zero. Nonetheless, assuming that, with greater numbers of participants and a larger number of pairs in each category studied, the current pattern of results would remain (albeit with increased power and significance), some interesting conclusions could be drawn.

The two within-domain pairings had lower levels of memory than the between-domain pairing. Indeed, the random noises within-domain pairing showed the lowest memory performance of all, with a mean score of exactly zero. These trends weakly suggest that forming associative memories between two different kinds of stimulus is easier than doing so between two of the same kind. The ‘environmental’ sounds and ‘random noises’ pairing produced the highest mean memory performance (at 0.18) which is highly likely, when tested with a greater number of pairs and participants to be significantly greater than chance. Between these two, the ‘environmental sounds’ pairings produced a memory performance of 0.13, which could reflect a real memory effect but, if it does, remains a very small one. It is interesting to note that associations between the same kind of stimulus (when lacking semantic content) are very difficult to remember, whilst pairs of the same kind of stimulus (when they have semantic content) are relatively easier. Drawing from these conclusions, memory performance in the visual associative task would have been even higher had the animal stimuli been paired with a different kind of visual stimulus, such as ‘abstract art’, which lacks semantic content. As noted before, these conclusions must be highly tentative because none of the auditory associative categories were
significantly above chance. In addition, the caveats relating to the environmental sounds as outlined in the discussion of Pilot Study 1 and Pilot Study 2 remain. It is possible that some of the environmental sounds were not recognised and as such, in fact, represented random noises. However, this should only have been present in a few instances, for some of the participants. Despite this, it reinforces the tentative nature of conclusions drawn from the analysis of the different kinds of pairs in the auditory task.

It would be interesting to consider these results in light of the Domain Dichotomy theory but this is impossible as participants were completing a standard yes/no associative recognition procedure and, therefore, will have used both familiarity and recollection to try to complete the task. Irrespective of whether or not familiarity supported any of the associations formed in either the auditory or visual associative tasks, many more participants would be needed in order to test the Domain Dichotomy theory with a variety of different kinds of pairs. This study sought to assess whether or not auditory stimuli could be remembered sufficiently well in a modified version of the standard yes/no associative recognition paradigm. Based on a single sequential presentation of the pairs of associative stimuli, memory performance was not above chance either when looking at the auditory pairs as a whole, or at each type of auditory association in turn. These same participants performed well (significantly above chance) in a standard ‘animal’ within-domain associative recognition experiment, ruling out the possibility that these results were participant dependent. These results, therefore, cast doubt on the feasibility of employing auditory stimuli, so that associative recognition can be compared without any confounds, with standard tests using visual stimuli.

I conclude, therefore, that while the use of auditory stimuli in associative tasks remains an interesting, and potentially plausible, line of research it is currently impractical to include them in any further analysis of the Domain Dichotomy theory.
General discussion of Part 1.

In Part 1 three pilot studies were conducted, exploring the potential use of auditory stimuli in associative recognition tasks. In addition, item recognition memory performance was assessed for a range of different kinds of stimulus while simultaneously providing information on the optimal spacing of item in a continuous recognition study paradigm. It was found that auditory stimuli could be very challenging for people to correctly identify. This makes preparation of many usable auditory stimuli very difficult. However, the successful preparation of a number of such identifiable stimuli suggests that, with further effort, such a task should be possible. These auditory stimuli were included in a simple yes/no continuous recognition task employing a number of different kinds of stimuli. Results showed that participants were, largely, able to recognise all the types of stimulus at the same level. Finally, participants who completed a standard yes/no associative recognition test (albeit with stimuli presented sequentially) using pairs of auditory stimuli performed very poorly, despite showing good memory on a conventional yes/no associative recognition test with visual stimuli. The difficulty in preparing and employing auditory stimuli in Pilot Studies 1 and 3 led to the decision not to employ auditory stimuli in the following experiment, despite the reasonable item recognition memory for some of those auditory stimuli Pilot Study 2.
**Part 2:**

**Associative Recognition Memory for different kinds of pairs: Matched Conditions**

**Introduction**

It has long been considered that associative recognition memory must be supported by recollection processes and by those structures (such as the hippocampus) that are associated with recollection (Yonelinas, 2002b). The general exception to this rule is when two or more items are unitised and so are processed as one item (Quamme, Yonelinas, & Norman, 2007). The Domain Dichotomy theory makes two useful contributions to the discussion of if and when familiarity processes should support associative recognition memory when more than one item seems to be involved (Mayes, et al., 2007).

The first contribution of the Domain Dichotomy theory is the clarification of when, and how, unitisation occurs (see Mayes et al., 2007; and Montaldi & Mayes, 2010 for a development of the theory). It is clear that, at least under certain circumstances, unitisation is a very common occurrence, with the majority of what would be considered items actually comprising multiple component parts (such as a car comprising wheels, windows and doors, etc.), that typically are automatically perceived as a single composite item. More specifically, unitisation may occur quickly when the component parts are spatially adjacent to each other and so form a spatial continuum provided that they are encoded in an appropriate way. This may occur, for example, when a person is encouraged to perceive two unrelated words, such as sea and turkey as one word naming one kind of thing (a bird like a turkey that lives like a seagull), although this may still take several learning trials and occur by degrees. When components that are already items,
such as faces or objects, are spatially non-continuous, it will be much harder to unitise them and this may take many trials and depend on thinking about the components in a very specific way, although, if it occurs, unitisation will occur by degrees. However, measuring degrees of unitisation is currently not possible unless one relies entirely on subjective ratings rather than on objective criteria. This would be easier to quantify but none are currently agreed.

The second contribution is based upon an examination of the neural substrates of familiarity and recollection. Assuming that item and associative recognition memory are supported by familiarity and recollection that each depends on specific processing mediated by different regions of the medial temporal lobes, the specific region in which any set of components converge and are mnemonically processed together will dictate which memory processes are involved in encoding the memory representation. This will determine whether recognition is supported by familiarity and/or recollection. For example, when items converge in the perirhinal cortex a non-unitised inter-item memory representation may be produced that allows associative recognition to be supported by associative familiarity, which is a feeling of familiarity that a pair of items previously went together.

It is plausible to conclude that different types of stimulus will enter the medial temporal lobes at different points owing to the large numbers of separate paths taken by neural inputs to these structures. What is uncertain is which paths various types of stimulus take and whether these separate paths result in functional differences in memory and its neural processing, because convergence of different kinds of item information occurs in more than one medial temporal lobe structure involved in mnemonically processing those inputs. It is natural to conclude that two similar stimuli (representing one category of stimulus) will feed into the same region of the medial temporal lobes and that it is possible that different types of stimulus will enter either a different structure or a different region of one structure. Should there be different entry points
for two different types of stimulus they may not be processed together until having been passed higher up the medial temporal lobe hierarchy to the hippocampus. Therefore, early convergence in the perirhinal cortex should mean, according to the Domain Dichotomy theory, that associative recognition is well supported by familiarity, whereas late convergence in the hippocampus should mean that associative recognition is very poorly supported by familiarity and must depend almost entirely on recollection. Based on the argument that similar kinds of inputs will converge earlier in the medial temporal lobe hierarchy, the earlier version of the theory (Mayes et al., 2007) predicted that within-domain associations converge early whereas between-domain associations will converge later, unless the item pairs have been strongly unitised.

This experiment, therefore, sought to determine whether or not differences can be found in the contribution of familiarity to the associative recognition of a number of different kinds of pairs. Multiple within-domain pairs (where the component stimuli are of the same category) were studied and tested, in both an associative familiarity-only and general associative recognition paradigm, using the two sets of results to calculate the relative proportion of overall associative recognition performance that was contributed by associative familiarity. The same procedure was employed with between-domain pairs (with component items from different categories of stimulus). Comparisons could, therefore, be made both between individual kinds of pairs (for example, animal pictures) and, more generically, between within- and between-domain pairs.
Method

Participants

Seventy four (fifty seven female) University of Manchester students took part in the experiment. The mean age of the participants was 21.7 (SD 2.4). Exclusion criteria included being a non-native English speaker and being left handed. As such all participants were native English speakers and were right handed. The study was approved by the School of Psychological Sciences Research Ethics Committee of the University of Manchester and informed consent was obtained from the participants. The participants received course credits for participation as part of their undergraduate degree in Psychology.

Procedure

Participants were randomly assigned to one of four different conditions. Participants completed either a within- or between-domain associative recognition memory test, employing either a standard associative recognition procedure or an associative familiarity-only procedure (Montaldi et al., 2006; Mayes et al., 2007). Those participants who completed the familiarity only procedure received detailed instructions regarding familiarity and recollection and were instructed not to try to recollect but to indicate that they had, should they inadvertently do so. In each case, the stimuli were studied and tested using the same procedure. Analysis for this experiment was based on a between participants design. This method of analysis is always affected by the confound that variations in performance may be due to differences in the participants and not reflect changes as a result of the psychological manipulation. However, this effect is controlled for by the random assignment of participants and the averaging of responses. The use of a within participants design would have been more statistically powerful, but would
also have risked possible confounds from potentially asymmetric order effects that would have been difficult to control by counterbalancing order. In the methodology used here, within- and between-domain pairs sometimes included the same types of stimulus. For instance, one within-domain condition involved pairs of animals and one between-domain condition involved pairs of animals and words. If participants had studied both types of pairs, there may have been an interference effect on their memory for those items included in both the within- and between-domain conditions. This may have affected their associative memory performance. In addition, a primary goal of the experiment was to test participants on several (four) different types of pairs. In order to avoid fatigue effects, in this challenging task, participants were only tested on one kind of domain manipulation.

Participants completed two study phases each consisting of 30 pairs of items presented for 3000ms separated by a 500ms fixation cross (+). They were instructed to “focus on how the pairs of items appear on the screen together”. This was in order to encourage associative familiarity encoding by forming direct links between component items as opposed to using an elaborative encoding task such as forming a story or single item comprising the objects. Immediately following the study phases, two test phases were completed. Half of each set of pairs remained in their original combinations while the other half were recombinations of previously seen items that had not been shown together (no items were tested more than once with any given participant to avoid confusion and interference effects). As at study, each pair was presented for 3000ms with 500ms fixation crosses. Participants were instructed to respond as quickly and accurately as possible while the pair of stimuli was displayed. Participants complete one of two different procedures. In the standard yes/no recognition procedure participants responded either that they thought they had seen the two items together, or that they thought that the two items were a new combination. In the familiarity-only procedure participants responded either that they thought a pair was a new combination or that the two stimuli had
been presented together previously, on the basis of a feeling that they had been encountered together beforehand. They were also told not to try to recollect, but to report whether this had occurred without their trying because the recollection had occurred involuntarily. In other words, their task was to indicate whether or not it felt familiar that pairs had occurred together earlier, but if they happened to recollect something that confirmed this, then they were asked to report it (see Montaldi et al., 2006 and Mayes et al., 2007). This entire procedure was repeated twice, resulting in four sets of pairs having been studied and tested. The order of the pairs was randomised across participants and trials. Example orders of presentation are shown below:

**Within-Domain**

- Study Names
- Study Animals
- Test Names
- Test Animals
- Study Art
- Study Scenes
- Test Art
- Test Scenes

**Between-Domain**

- Study Animals & Words
- Study Scenes & Tools
- Test Animals & Words
- Test Scenes & Tools
• Study Art & Names
• Study Faces & Names
• Test Art & Names
• Test Faces & Names

Stimuli

Several categories of stimuli were the same as those used in Study 2 of Part 1. When this was the case the stimuli were drawn from the same collection using the same criteria. In addition to these stimuli, several new classes of stimulus were employed. These included male and female names and abstract art. A full list of stimulus types is listed below:

- Male names;
- Female names;
- Abstract Art;
- Scenes;
- Animals;
- Written Words;
- Tools;
- Faces.

Names

The Male and Female names were taken from an online source of the top 100 male and female baby names in 2004 (www.parents.com/baby-names/popular).
Abstract Art

The abstract art were drawn for a pre-existing database. See Figure 10 for examples.

Figure 10. Examples of Abstract Art Stimuli.
Animals

The category of animal stimuli was used as had been the case in Pilot Study 2 and so do not represent a new category of stimuli. However, different stimuli were used. In contrast to the previous images, which comprised line drawings with minimal colour shading, full colour, high resolution photographs were employed. See Figure 11 for examples.

**Figure 11.** Examples of new animal stimuli.
In the within-domain condition, participants studied pairs that comprised:

Male names;
Animals;
Abstract Art;
Scenes.

In the between-domain condition, participants studied pairs that comprised:

Animals and words;
Scenes and tools;
Art and male names;
Female Faces and female names.

**Results**

Yes/No Associative Recognition Results

Associative recognition memory as measured by the Hit Rate minus False Alarm Rate ranged from 0.22 to 0.48 (mean 0.34) in the within-domain condition and 0.30 to 0.67 (mean 0.49) in the between-domain condition. All mean recognition scores were significantly different from zero. All effects are reported as significant at p<0.05.

Within domain:

Names ($T_{(18)} = 7.439, p<0.001$).
Animals ($T_{(18)} = 15.133, p<0.001$).
Abstract Art ($T_{(18)} = 5.924, p<0.001$).
Scenes ($T_{(18)} = 9.914, p<0.001$).
Between domain:

Animals and Words ($T_{(22)} = 13.35, p<0.001$).

Scenes and Tools ($T_{(22)} = 15.487, p<0.001$).

Abstract Art and Names ($T_{(22)} = 6,722, p<0.001$).

Faces and Names ($T_{(22)} = 5.731, p<0.001$).

Repeated measures ANOVAs were conducted in order to explore whether there were significant differences in associative recognition memory performance for the different pairings in both the within- and between-domain conditions. In the within-domain condition, there was a significant effect of the type of pair to be recognised ($F_{(3,54)} = 9.875, p<0.001$). Bonferoni post-hoc analysis showed that recognition of the ‘animal’ pairs was significantly higher than the ‘abstract art’ pairs ($p<0.001$) and the ‘scene’ pairs ($p<0.05$) while there was a trend for ‘animal’ pair associative recognition to be higher than ‘name’ pairs ($p=0.06$). In addition, ‘abstract art’ pairs were recognised significantly less well than ‘scene’ pairs ($p<0.05$). In the between-domain condition, there was a significant effect of the type of pair to be recognised ($F_{(3,69)} = 20.320, p<0.001$). Bonferoni post-hoc analysis showed that ‘animal’ and ‘word’ pairs were recognised significantly better than either ‘abstract art’ and ‘name’ pairs ($p<0.05$) or ‘face’ and ‘name’ pairs ($p<0.001$) and that recognition of ‘scene’ and ‘tool’ pairs was significantly better than either ‘abstract art’ and ‘name’ pair associative recognition ($p<0.001$) or ‘face’ and ‘name’ pairs ($p<0.001$).

Familiarity-Only Results

The use of the familiarity only procedure was successful in producing only a small number of recollection hit responses. The recollection responses represent less than 10 percent of the overall number of responses. The mean hit rate in the within-domain condition was 0.10
(SD 0.05) while the false alarm rate was 0.03 (SD 0.01). The hit rate minus false alarm rate for the mean within-domain recollection responses was 0.07 (SD 0.06).

The mean hit rate in the between-domain condition was 0.17 (SD 0.07) while the false alarm rate was 0.01 (SD 0.01). The hit rate minus false alarm rate for the mean between-domain recollection responses was 0.16 (SD 0.07).

Between samples t-tests showed that there was no significant difference between the hit rates of the within- and between-domain conditions for the recollection responses ($T_{(30)} = -1.291$ $p=0.387$), the false alarm rates ($T_{(30)} = -0.343$ $p=0.734$). However, there was a strong trend towards there being a significant difference between the hits minus false alarm memory performance score based on recollection responses between the two conditions (equal variances not assumed) ($T_{(24,203)} = -2.048$ $p=0.052$).

The mean hit rate for all of the types of pairs based on familiarity was 0.49 with a false alarm rate of 0.32 while the mean hit rate and false alarm rate for recollections was 0.14 and 0.03 respectively. When the hit rates for familiarity and recollection were combined and then the combined false alarm rates for familiarity and recollection were subtracted, a mean performance score of 0.27 was produced. This contrasted with a Yes/No recognition mean memory performance score of 0.42. An independent samples t-test was conducted comparing the mean performance of each participant in the familiarity only condition with the mean performance in the Yes/No recognition condition. Memory performance was significantly higher in the Yes/No recognition condition (0.42) than in the familiarity only condition (0.27) ($T_{(72)} = -3.869$ $p<0.001$). See Table 4.
Table 4.

Hit rate and false alarm rates for each type of pair under the familiarity only procedure (familiarity and recollection) and the Yes/No recognition procedure.

Familiarity performance was calculated three times (hit rate minus false alarm rate), using the exclusivity, independence and redundancy assumptions. For exclusivity, the familiarity hit rate was based on the assumption that recollection and familiarity occur in a mutually exclusive way so that the familiarity hit rate is equal to the number of old associations judged familiar as a proportion of the total number of old or studied associations. A similar calculation was used to calculate the familiarity false alarm rate except that the numerator was the number of recombined (‘new’) pairs. Under the independence assumption, it was assumed that familiarity is equally likely to occur for recollected as for unrecollected studied (or new pair) associations so the familiarity hit rate was equal to the proportion of unrecollected studied pairs that were found to be familiar (with a similar calculation being used to identify the false alarm rate). Finally, redundancy assumes that all recollected associations will be familiar so the familiarity hit rate is equal to the sum of the proportion of studied pairs that were either found to be familiar or which triggered diagnostic recollection and the false alarm rate was calculated in the same way (see Mayes et al., 2007). It is important to realize that summing familiarity and recollection scores from the familiarity only procedure will probably not yield a score as high as that found in the
recognition procedure. This is because recollection levels will have been lower in the familiarity only procedure as only involuntary recollection should have occurred. With recognition, it is likely that some recollection would be effortful so the difference between the recognition scores from the familiarity only and recognition procedures is an indication of how well the familiarity only procedure worked.

Comparing the estimates of familiarity, using the three different assumptions of exclusivity, independence and redundancy, is difficult statistically given that the resultant data is the product of different manipulations of the same original data. This being the case, technically, the results are not truly independent as would be expected under normal conditions. Nonetheless, treating the data as independent can be informative in trying to establish whether or not relatively small differences in the absolute numbers might represent significant differences. However, this analysis is not included in the discussion.

A mixed design 2x3 ANOVA was conducted so as to assess whether there were significant differences between the familiarity scores produced by using the three different assumptions. Sphericity was violated and so Greenhouse-Geisser corrections were employed. There was a significant main effect of the kind of method used to calculate associative familiarity with the exclusivity assumption suggesting the lowest level of familiarity memory (within-domain 0.12, SD 0.21:between-domain 0.21. SD 0.25), the independence greater (within-domain 0.17, SD 0.22:between-domain 0.30. SD 0.26), and the redundancy greater still (within-domain 0.19, SD 0.21:between-domain 0.34. SD 0.26) (\(F_{(1,129,33,857)} = 27.479, p<0.05\)). The main effect of type of association (within- or between-domain) was significant with greater levels of performance in the familiarity only condition in the between-domain pairs than in the within-domain pairs (\(F_{(1,30)} = 5.661, p<0.05\)). There was no interaction between the familiarity calculation method and the type of association (\(F_{(1,129,33,857}, p<0.05) = 3.015\)). The contribution of familiarity to overall
recognition performance was calculated by deriving the proportion of the mean recognition score that was contributed by the mean familiarity score. The familiarity scores, recognition scores and the proportion of overall associative recognition constituted by associative familiarity for all three calculation methods (exclusivity, independence and redundancy) are outlined in tables 5, 6, and 7. All subsequent analysis is conducted using the independence assumption owing to the fact that the independence assumption is the most widely used and discussed assumption in the literature.
### Exclusivity

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Recognition</th>
<th>Proportions %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within</strong></td>
<td>Hit Rate - False Alarm Rate</td>
<td>Hit Rate - False Alarm Rate</td>
<td></td>
</tr>
<tr>
<td>Names</td>
<td>0.09 (0.21)*</td>
<td>0.32 (0.19)</td>
<td>28.13</td>
</tr>
<tr>
<td>Animals</td>
<td>0.23 (0.22)</td>
<td>0.48 (0.14)</td>
<td>47.92</td>
</tr>
<tr>
<td>Art</td>
<td>0.02 (0.18)*</td>
<td>0.22 (0.16)</td>
<td>9.09</td>
</tr>
<tr>
<td>Scenes</td>
<td>0.14 (0.22)</td>
<td>0.33 (0.15)</td>
<td>42.42</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>0.12 (0.21)</strong></td>
<td><strong>0.34 (0.16)</strong></td>
<td><strong>35.29</strong></td>
</tr>
<tr>
<td><strong>Between</strong></td>
<td>Familiarity</td>
<td>Recognition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hit Rate - False Alarm Rate</td>
<td>Hit Rate - False Alarm Rate</td>
<td></td>
</tr>
<tr>
<td>Animals &amp; Words</td>
<td>0.29 (0.26)</td>
<td>0.62 (0.22)</td>
<td>46.96</td>
</tr>
<tr>
<td>Scenes &amp; Tools</td>
<td>0.21 (0.29)</td>
<td>0.67 (0.21)</td>
<td>31.11</td>
</tr>
<tr>
<td>Art &amp; Names</td>
<td>0.20 (0.21)</td>
<td>0.38 (0.27)</td>
<td>51.87</td>
</tr>
<tr>
<td>Faces &amp; Names</td>
<td>0.13 (0.21)</td>
<td>0.30 (0.25)</td>
<td>41.53</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>0.21 (0.25)</strong></td>
<td><strong>0.49 (0.24)</strong></td>
<td><strong>42.87</strong></td>
</tr>
</tbody>
</table>

**Table. 5.**

The memory performance in all four conditions (within-domain familiarity and recollection, between-domain familiarity and recollection) calculated as Hit Rate-False Alarm Rate with Standard Deviations as calculated using the Exclusivity assumption. Those scores marked by an asterisk (*) were not significantly different from zero.
Redundancy

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Recognition</th>
<th>Proportions %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hit Rate – False Alarm Rate</td>
<td>Hit Rate – False Alarm Rate</td>
<td></td>
</tr>
<tr>
<td>Names</td>
<td>0.24 (0.21)</td>
<td>0.32 (0.19)</td>
<td>75.00</td>
</tr>
<tr>
<td>Animals</td>
<td>0.31 (0.20)</td>
<td>0.48 (0.14)</td>
<td>64.58</td>
</tr>
<tr>
<td>Art</td>
<td>0.04 (0.19)*</td>
<td>0.22 (0.16)</td>
<td>18.18</td>
</tr>
<tr>
<td>Scenes</td>
<td>0.17 (0.25)</td>
<td>0.33 (0.15)</td>
<td>51.52</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>0.19 (0.21)</strong></td>
<td><strong>0.34 (0.16)</strong></td>
<td><strong>52.32</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Recognition</th>
<th>Proportions %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hit Rate - False Alarm Rate</td>
<td>Hit Rate - False Alarm Rate</td>
<td></td>
</tr>
<tr>
<td>Animals &amp; Words</td>
<td>0.47 (0.29)</td>
<td>0.62 (0.22)</td>
<td>75.81</td>
</tr>
<tr>
<td>Scenes &amp; Tools</td>
<td>0.43 (0.26)</td>
<td>0.67 (0.21)</td>
<td>64.18</td>
</tr>
<tr>
<td>Art &amp; Names</td>
<td>0.27 (0.27)</td>
<td>0.38 (0.27)</td>
<td>71.05</td>
</tr>
<tr>
<td>Faces &amp; Names</td>
<td>0.19 (0.20)</td>
<td>0.30 (0.25)</td>
<td>63.33</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>0.34 (0.26)</strong></td>
<td><strong>0.49 (0.24)</strong></td>
<td><strong>68.59</strong></td>
</tr>
</tbody>
</table>

**Table. 6.**

The memory performance in all four conditions (within-domain familiarity and recollection, between-domain familiarity and recollection) calculated as Hit Rate-False Alarm Rate with Standard Deviations as calculated using the Redundancy assumption. Those scores marked by an asterisk (*) were not significantly different from zero.
### Table 7.

The memory performance in all four conditions (within-domain familiarity and recollection, between-domain familiarity and recollection) calculated as Hit Rate-False Alarm Rate with Standard Deviations as calculated using the Independence assumption. Those scores marked by an asterisk (*) were not significantly different from zero.
Using the Independence assumption a series of one sample t-tests was conducted in order to compare the familiarity performance scores against zero. All categories were significantly different from zero, except the ‘abstract art’ within-domain category.

**Between:**

- Animals and Words \( (T_{17} = 5.722, \ p<0.001) \).
- Scenes and Tools \( (T_{17} = 5.422, \ p<0.001) \).
- Abstract Art and Names \( (T_{17} = 4.002, \ p=0.001) \).
- Faces and Names \( (T_{17} = 3.540, \ p=0.003) \).

**Within:**

- Names \( (T_{13} = 2.813, \ p=0.015) \).
- Animals \( (T_{13} = 5.108, \ p<0.001) \).
- Abstract Art \( (T_{13} = 0.646, \ p=0.530) \).
- Scenes \( (T_{13} = 2.481, \ p=0.028) \).

Repeated measures ANOVAs were conducted in order to explore whether there were significant differences in familiarity memory performance for the different pairings in both the within- and between-domain conditions. In the within-domain condition there was a significant effect of the type of pair to be remembered \( (F_{(3,39)} = 4.949, \ p<0.05) \). Bonferoni post hoc analysis showed that ‘animal’ pairs were better recognised than the ‘abstract art’ pairs \( (p<0.05) \). In the between-domain condition there was a significant effect of the type of pair to be remembered \( (F_{(3,31)} = 3.428, \ p<0.05) \). LSD post hoc analysis showed that ‘animal’ and ‘word’ pairs were significantly better recognised than ‘abstract art’ and ‘names’ pairs \( (p<0.05) \) and ‘face’ and ‘name’ pairs \( (p<0.05) \). In addition, ‘scene’ and ‘tool’ pairs were significantly better recognised than ‘face’ and ‘name’ pairs \( (p<0.05) \).

Average memory performance in the familiarity only condition was significantly higher in the between-domain condition (0.30) than in the within-domain condition (0.17) \( (T_{30} = 2.299, \ p<0.05) \).
Average recognition memory performance was also higher in the between-domain (0.49) than in the within-domain condition (0.34) [Levene’s Test for Equality of Variances was significant so the test was conducted using modified degrees of freedom to compensate] ($T_{(36.449)} = 3.733, p<0.05$). Using a between participant t-tests there were no significant differences between the mean contribution of familiarity to the overall associative recognition score: Independence ($T_{(30)} = 0.734, p>0.05$).

Analyses were conducted looking at those within-domain pairs that were the components of a between-domain pair. In this experiment only one between-domain pair had each of its component types of stimulus also tested as within-domain pairs. This was the ‘abstract art’ and ‘names’ between-domain pairing, with the ‘abstract art’ and the ‘names’ having been tested in the within-domain condition. There was no significant difference between associative recognition performance for the ‘abstract art’ and ‘name’ within-domain pairs ($T_{(18)} = -1.685, p=0.109$). As there was no significant difference between associative recognition of the two within-domain pairs, their mean was taken (0.27) and this was compared to the recognition performance for the between-domain combination of the two types of stimulus. As the mean recognition performance for the between-domain associations was significantly greater than was the case in the within-domain condition, a one-tailed between participants t-test was conducted. It was found that recognition performance (Levene’s Test for Equality of Variances was significant so the test was conducted using modified degrees of freedom to compensate) for the between-domain condition of abstract art paired with names was significantly higher than the mean recognition score of the two within-domain conditions ($T_{(33.895)} = -1.788, p<0.05$).

The hit rate minus false alarm rates for yes/no associative recognition, familiarity associative recognition and the proportion of familiarity contributing to that overall recognition performance are illustrated in Figures 12, 13 and 14 respectively.
Figure 12.
Hit rates minus false alarm rates of recognition memory for the different kinds of association.

Figure 13.
Hit rates minus false alarm rates of absolute familiarity memory for the different kinds of association.
Figure 14.

Proportions of recognition performance as contributed by familiarity using the independence assumption for the different kinds of association.

Discussion

This experiment sought to compare associative recognition (using a familiarity-only procedure) across several different within- and between-pair associations, some of which included overlapping kinds of items (for example, abstract art which are used in a within-domain pairing and as half of a between-domain pairing). In addition, it looked at levels of familiarity for those kinds of associations as proportions of associative recognition in a standard yes/no associative recognition task for the same kinds of association. Unless otherwise stated, the results discussed here were calculated using the independence assumption. As proposed by the Domain Dichotomy theory, and found by other researchers, participants were able correctly to identify previously studied pairs of items without recourse to recollection (Bastin, et al., 2010; Harlow, MacKenzie, & Donaldson, 2010). However, contrary to the Domain Dichotomy theory, under the matched study and test conditions maintained in this experiment, after study, the
discrimination scores for associative familiarity were higher for between-domain pairs than for within-domain pairs. However, this difference was mirrored by higher levels of associative recognition memory for between-domain pairs than for within-domain pairs in a standard yes/no recognition test. It is feasible that irrelevant factors that are unrelated to the claims of the Domain Dichotomy view lead to higher levels of associative recognition memory, and these factors also lead directly to higher levels of absolute familiarity memory. When this difference in standard yes/no associative recognition was taken into account, by calculating familiarity as a proportion of the corresponding yes/no recognition score, there was no significant difference between the contribution of familiarity to within- or between-domain pairs.

Participants completed one of two procedures, the first being a conventional yes/no recognition task while the second employed a familiarity-only procedure. The familiarity-only procedure was successful in reducing the number of recollection responses to below 10 percent of the total number of responses, consistent with the number of recollections as a proportion of total responses produced by previous studies which have used this technique successfully (Montaldi, et al., 2006). When associative recognition memory performance was calculated as the combined hit rate of familiarity (using the exclusivity assumption) and the hit rate of the recollection responses minus their corresponding false alarm rates, performance (0.27) was significantly below that of participants completing the standard yes/no (0.42) procedure. This strongly supports the conclusion that the familiarity-only procedure managed to minimise the number of recollection responses successfully and that those recollection responses that were made during the familiarity-only task represented spontaneously produced (inadvertent) recollections that probably did not involve effort.

Despite the relatively small number of recollection responses, familiarity performance when calculated using the three different assumptions (exclusivity, independence and
redundancy) varied, although the difference was quite small. The average hit rate minus false alarm rate for within- and between-domain pairs was 0.27 under the redundancy assumption and 0.17 under the exclusivity assumption (these two assumptions produce the extreme familiarity estimates with the independence assumption producing a score between the two with its precise position depending on the proportion of recollections). The assumption of redundancy increased the calculated familiarity performance to 160% of the familiarity performance based on the exclusivity assumption. This variation in calculated familiarity performance as a function of the assumption used to calculate it can be contrasted with other implementations of the familiarity-only procedure. For instance, Harlow, MacKenzie and Donaldson (2010) also utilised the familiarity-only procedure, resulting in a somewhat larger difference between the memory performance assuming exclusivity and redundancy. Their average (taken from the within- and between-domain averages) for the redundancy assumption was 0.46 while under the exclusivity assumption it was 0.16; the familiarity performance level calculated on the basis of the redundancy calculation was 314% the size of the level calculated on the basis of the exclusivity assumption. The substantial difference between these two studies with respect to how much the familiarity estimate varied as a function of whether the redundancy or exclusivity assumption was made suggests that participants in the present study were better able to implement the familiarity-only procedure. It is very probable that this was because overall recognition memory was weaker in the work reported in this thesis, so there were few involuntary recollections. If memory had been very strong, as perhaps in the Harlow and colleagues study, a higher proportion of involuntary recollections would have been found, much as with the standard variant of the remember/know procedure in which familiarity estimates are greatly affected by the underlying statistical assumption. The implications of a less effectively employed familiarity-only procedure are difficult to quantify precisely, although this cannot be a good thing when the aim is to obtain a reliable estimate of familiarity that is little affected by the statistical assumption made.
Associative recognition memory was significantly higher than chance in all cases while avoiding ceiling effects, which is necessary in order to facilitate meaningful calculations of familiarity proportions. It is informative to note these results in light of the findings in Pilot Study 2, which demonstrated that there were not substantial differences in item memory performance for a variety of the component stimuli. If, despite the presence of only minor differences in item recognition memory for different kinds of stimulus, there had been an extreme range of associative recognition memory performance for pairs consisting of those items (for instance floor or ceiling effects for some but not all pairs), the results would have suggested that the relationship, between item memory for the images (in this case) comprising a pair (when studied on their own) and associative memory (for those items when studied as pairs), is highly complex. This was not the case, with neither floor nor ceiling effects being present in any of the yes/no recognition condition for any of the pairs tested.

In all but one instance (abstract art within-domain pairings), participants were able to distinguish between original and recombined pairs (the average hit rate minus false alarm rate for both within- and between-domain pairs was 0.24) in the familiarity-only condition, suggesting that associative familiarity memory can support memory for associative pairs in the absence of (high levels of) recollection. Interestingly, the between-domain pairs had a higher mean hit rate minus false alarm rate score than the within-domain pairs (0.30 and 0.17 respectively). This runs directly counter to the shallow Domain Dichotomy theory and is similar to those findings of Harlow and colleagues (2010), who found that familiarity performance was better for between-domain pairs consisting of names and abstract images than for the matching within-domain pairs, although this was not the case for Bastin and colleagues (2010), who found results in line with the conventional predictions of the theory. While these findings that there is greater associative familiarity memory for between-domain pairs using absolute calculations of
familiarity run counter to the Domain Dichotomy theory, they also run counter to other dual-process theories of recognition memory, such as the BIC model, which would suggest that familiarity can only support intra-item recognition memory, a phenomenon that occurs when two items have been unitised (Diana, et al., 2007).

The above findings that absolute associative familiarity for between-domain pairs is greater than it is for within-domain pairs, and that it is well above chance usually for both kinds of pair are interesting in and of themselves. They suggest the need to reconsider the commonly held assumption that familiarity is unable to support associative recognition memory and lends support to a modified version of the Domain Dichotomy theory. However, more detailed analysis can shed further light on the relationship between familiarity and the two types of association (within- and between-domain) as employed in this experiment. Although recognition and familiarity memory performance was above chance across almost all pairs (with the exception of the within-domain abstract art pairs under the familiarity-only procedure), there was considerable variation in performance across the types of pairs studied. This confirms the necessity of testing multiple, and varied, types of pairs and of measuring the contribution of familiarity to each of the resulting recognition memory scores. It also indicates the need to calculate familiarity as a proportion of standard recognition.

Failure to calculate associative familiarity as a proportion of associative recognition for any given pair by just calculating absolute levels of associative familiarity may be misleading. The reason is that associative recognition levels of different kinds of association and for within-domain versus between-domain associations may differ for reasons that have nothing to do with what the Domain Dichotomy view states. For example, absolute familiarity levels of some of the within-domain associations differ from each other, as do the levels of associative recognition. It seems likely that these differences arise because some kinds of item are harder to learn, or
because it is harder to find appropriate ways of encoding some kinds of pair together (for example, abstract art pictures), or some other (as yet unspecified) reason, but not because certain kinds of association are better mnemonically processed in the perirhinal cortex than others. The central claim of the Domain Dichotomy view is that certain kinds of association are mnemonically processed in the perirhinal cortex and that others are not, and this plays a major (but not sole) role in determining how much familiarity there is. The use of a proportional measure of familiarity largely eliminates the contribution of other factors to levels of familiarity. When familiarity was calculated as a proportion of the corresponding yes/no recognition test there was no significant difference in familiarity performance between within- and between-domain pairs. It is very important to point out that this finding is inconsistent with the earlier form of the Domain Dichotomy view, which stated that within-domain associations should be much better supported by associative familiarity than between-domain associations. Nonetheless, it may be that absolute levels of associative familiarity are typically higher for between-domain pairs than for within-domain pairs and that this reflects the higher level of associative recognition that is shown for between-domain associations. This simply indicates that some kinds of pairs are generally much harder to learn (because of factors unrelated to the medial temporal lobes) and within-domain associations may be harder to learn as a group because it is harder to find appropriate associative encoding techniques for them.

As noted above, these results are inconsistent with the standard shallow version of the Domain Dichotomy theory, while they are also inconsistent with the main alternative theory, the BIC model, which proposes that familiarity should only be able to support associative recognition memory when pairs of items have been unitised. Unitisation will now be discussed within the context of the Domain Dichotomy theory. Although kinds of encoding that support unitisation are probably automatic for associations comprising adjacent components that form a spatial continuum, the Domain Dichotomy view allows that inter-item associative encoding
depends on selection of appropriate ways of encoding. This may be an effortful process, the
difficulty of which varies as a function of the kinds of pair being associated, and, in particular, of
whether they are between- or within-domain associates.

In this thesis, I am assuming that the associations that have been reported here are
primarily inter-item, although a small amount of unitisation may have been occurring. This is
assumed because all associated items are spatially separated and people typically report that, after
encoding, if the stimuli feel familiar, that this familiarity is for the feeling that the two items were
previously experienced together and not that ‘this stimulus’ feels familiar. With spatially
separated components, therefore, unitisation is likely to take many trials before it is complete (if
it ever becomes so), although the conditions that facilitate unitisation for spatially separated
components need to be clarified. Previous studies weakly suggest that it is more likely to occur
when pre-existing associations exist between two items, or when special encoding instructions
are used to encourage unitisation at study (Quamme, et al., 2007; Rhodes & Donaldson, 2008).
Neither of these conditions was more present in the between-domain associates in the present
study. The stimuli included were novel stimuli, randomly paired so that pre-existing associations
should not exist. In addition, the encoding instructions emphasised the need to focus on the
stimuli as they appeared without directing participants to form new compound items such as
used by Quamme and colleagues (2007). Nonetheless, it is possible that between-domain pairs
could lend themselves better to unitisation than within-domain pairs. For instance, it might be
more natural to come to feel, after relatively little study time, that a face and a name have
somehow become a new higher level entity than is the case with two animals. The impact of
unitisation remains difficult to detect and measure and differences between the two domains
cannot be meaningfully considered.
There was only one case in the experiment where familiarity performance was not above chance. This was the within-domain pairing of abstract art stimuli. Although not included in Pilot Study 2, memory for ‘abstract art’ items was assessed in the subsequent fMRI study (Chapter 3). Item memory performance for the abstract art items was second lowest in that continuous recognition familiarity-only study, only slightly above the category of faces and significantly lower than tool or animal stimuli; however, it was far above chance. Furthermore, associative recognition memory performance in the yes/no procedure for this kind of pair was the lowest of all of the associative pairs tested. Despite the majority of pairs being well remembered, given the matched study conditions, it is apparent that memory for ‘abstract art’ (both as items, and especially as pairs) is naturally lower than that for other types of pairs. It is possible that an enhanced opportunity (for example, more encoding time) for encoding and/or the use of a more appropriate associative encoding strategy with this type of pair should produce a more robust recognition performance, which would elicit an above chance contribution of familiarity.

While the use of the proportional measure of familiarity did not find a higher level of familiarity support for between-domain associations, which would be the opposite of that postulated by the Domain Dichotomy theory, it failed to find that levels of associative familiarity were significantly higher for within-domain associations, as the original version of the hypothesis at least weakly proposed. However, as indicated earlier in this thesis, the deeper version of the hypothesis is that familiarity support will be stronger (in proportional terms) for inter-item associations that are mnemonically integrated in the perirhinal cortex than for inter-item associations that are not integrated there, but primarily in the hippocampus. This postulate can only be tested by examining the neural predictions of the hypothesis using some kind of brain imaging method. The present finding and those of Harlow and colleagues (2010) challenge all previous accounts of associative recognition and associative familiarity, provided one assumes
that levels of unitisation are low, which seems intuitively plausible. The finding suggests that many cross-category associations may be processed well within the perirhinal cortex, which is believed to receive all kinds of object stimulus inputs (or inputs that may be represented, like some scenes, in terms of their constituent items). This proposal does, nevertheless, need to be confirmed, or invalidated, through the use of brain imaging methods.

There is one study that found a pattern of results that is compatible with the earliest version of the Domain Dichotomy view. Thus, Bastin and colleagues (2010) conducted an experiment with the similar goal of comparing the proportional contribution of associative familiarity to within- and between-domain pair associative recognition, and found that associative familiarity contributed significantly more to within-domain pair recognition. These workers sought to match associative recognition performance, albeit imperfectly, by using different levels of training in order to allow a more direct comparison of associative familiarity performance. As an extension of the direct comparison, allowing for the imperfect matching of recognition performance, comparisons of the contribution of familiarity were made based on the measurement of the proportion of overall recognition performance. This approach avoids confounding associative familiarity and associative recognition levels as experienced by Harlow and colleagues (2010) and was more similar to the approach taken in the experiment reported in this chapter.

The results in the Bastin and colleagues (2010) paper differ from those of Harlow and colleagues as well as those reported in this chapter. While methodological issues exist with the Harlow and colleagues study, the biggest difference between the Bastin and colleagues study and the other two is that fewer kinds of association were investigated. While the use of four different kinds of pair does not represent an exhaustive exploration of potential pairings, the use of a number of different types of pairs allows broader conclusions to be drawn. In one respect, these
three studies share the finding of familiarity supporting associative recognition memory, irrespective of whether the component items are from the same, or different, categories. The different pattern found by Bastin and colleagues could mean that no one pattern applies to all within-domain or all between-domain associations.

As stated throughout this thesis, the Domain Dichotomy theory makes the prediction that within-domain categories are likely to be supported by familiarity more often, or to a greater degree, than would be the case with between-domain categories. Nonetheless, the developed form of the theory considers the possibility that ‘domain’, as indicated above, may not be equivalent to whether components come from the same or different categories, but rather may depend on whether components are integrated within the perirhinal cortex or, possibly, also within the parahippocampal cortex. As indicated above, it remains to be tested what kinds of associations are processed mnemonically within different parts of the medial temporal lobes, which is the proper way to determine whether the Domain Dichotomy view is correct or mistaken in postulating that associative familiarity is a function of the perirhinal cortex (and possibly also the parahippocampal cortex), but not of the hippocampus. Intuitively, stimuli should be processed by non-identical medial temporal lobe sites if they differ substantially in perceptual and semantic content. However, intuitions may be incorrect, so the need to examine where associative memory representations are integrated in the medial temporal lobes is obvious. A start will be made on this kind of examination in the experiment reported in the next chapter.

In the absence of neuroimaging data, it is, at least clear, that associative familiarity is not stronger for within-category pairs than it is for between-category pairs, so the Domain Dichotomy hypothesis’ early postulation that this should be so is clearly wrong, even if there are cases that it can deal with adequately (for example, as with the study by Bastin et al., 2010). The deeper question remains to be explored, viz., if the perirhinal cortex (and possibly the
parahippocampal cortex) creates familiarity-supporting memory representations, does it create such representations for inter-item as well as intra-item (unitised) associations when these converge for mnemonic processing with its neurons?

In conclusion, the research reported in this chapter has found that associative recognition memory performance was generally (but not always) greater than chance, but, more importantly, it also found that this was also true of associative familiarity. This is in direct contrast to the conclusions of previous research that suggested that associative recognition memory is exclusively supported by recollection (for example Hockley, 1992). The proportional contribution of associative familiarity to associative recognition was closely similar for within- and between-domain associations, which indicates that the earlier and superficial prediction of the Domain Dichotomy hypothesis was wrong. However, it remains possible that between-domain associations are also processed in the perirhinal or parahippocampal cortices, so that the deeper version of the hypothesis can still be true. A preliminary attempt to investigate this possibility will be reported in the next chapter.
Chapter 3: An fMRI study of familiarity for different kinds of stimulus items

Introduction

The Domain Dichotomy theory makes specific predictions about the conditions under which familiarity can support associative memory (Mayes, et al., 2007; Montaldi & Mayes, 2010). According to the theory, those pairs of stimuli classed as within-domain should converge earlier within the medial temporal lobe hierarchy, in neocortical structures, such as the perirhinal or parahippocampal cortices. These medial temporal lobe regions have a cytoarchitectonic structure that enables them, under certain conditions (such as appropriate kinds of encoding), to bind together some of their inputs so as to create inter-item as well as intra-item associative memory representations that, at least after one or two study trials, are very poorly pattern separated. This means that they can support familiarity well but recollection very poorly. In other words, the processing supported by the perirhinal and parahippocampal cortices binds together pairs of stimuli that each cortex receives into associative representations that, when activated, produce a familiarity signal, or feeling, that the two stimuli have been presented before.

The deepest claim of the theory is, therefore, that these structures rapidly create inter- and intra-component/item associative memory representations from whatever items/components that converge for processing within their neurons and these representations support familiarity well and recollection very poorly. The second, slightly less deep claim is that information from the same category, or very similar categories, is likely to converge in this cortex whereas information from very different categories (and that is very dissimilar) may only converge in the hippocampus. In other words, this is the claim about the difference between within- and between-domain associations. Associative familiarity is in addition to any feeling of familiarity for the component items (and even with reduced familiarity for those components) or
recollected information diagnostic of their original pairing. In contrast, between-domain pairs should converge only at the apex of the hierarchy of the medial temporal lobes, that is, in the hippocampus. Here, pattern separation mechanisms facilitate flexible representations of the encoded stimulus and are related to recollection processes.

This hypothesis was constructed on the basis of clinical trials that found that patients with hippocampal damage (reducing recollection memory while sparing familiarity) showed reduced performance on many associative memory tasks whilst exhibiting intact performance in experiments where the stimuli to be recognised were from the same domain category (Mayes, et al., 2004; Vargha-Khadem, et al., 1997). A couple of studies (and the experiments in the previous chapter) have sought to test the hypothesis by testing healthy participants on associative recognition experiments looking specifically for the contributions of familiarity. The findings from the previous chapter indicate that associative familiarity supports associative recognition for between-domain associations just as well as it supports within-domain associations. This finding is incompatible with the less deep claim of the domain dichotomy view, viz., that only within-domain associative recognition will be well supported by associative familiarity. However, the finding may still be compatible with the deeper claim of the hypothesis that only object information that converges for mnemonic processing within the perirhinal cortex (and possibly the parahippocampal cortex), although the recent update of the hypothesis proposes that the parahippocampal cortex creates memory representations involving context that support associative familiarity well (Montaldi & Mayes, 2010).

Contrary to traditional theories, recognition memory for pairs of stimuli seems to be supported by familiarity in the absence of recollection and in a way which unitisation is unlikely to explain. These results have been produced by three distinct sets of researchers in varied geographic regions, using distinct population groups as participants. All three sets of researchers
have sought to employ the familiarity-only procedure, a modified remember/know paradigm albeit with slightly different experimental designs. For instance different numbers of pairs were used: Bastin and colleagues (2010) used the least with only two sets of pairs (one within- and one between-domain), Harlow and colleagues (2010) used three different sets of pairs (two within- and one between-domain pair) and the research in the previous chapter used eight (four sets of pairs for both the within- and between-domain conditions). In addition, while Bastin and colleagues and the experiment in Chapter 2 used a standard yes/no recognition paradigm in concert with the familiarity-only procedure, Harlow and colleagues used a “recollection” paradigm in which recall of some aspect of the original presentation was required regardless of confidence. Finally Harlow and colleagues also employed an ROC analysis procedure to produce corroborating results based on different assumptions. Nonetheless, while it is becoming increasingly likely that familiarity is able to accurately support associative recognition memory, the circumstances under which it is able to do so remain less clear. One set of results seems to support the conclusion that recognition of within-domain pairs of stimuli is better supported by familiarity than is recognition of between-domain pairs (Bastin, et al., 2010). However, associative recognition of between-domain pairs was also supported by familiarity, albeit to a lesser degree. Harlow and colleagues (2010) compared associative recognition of two within-domain pairs with that of one between-domain pair and found that familiarity equally supported the between-domain pair and one of the within-domain pairs but supported recognition of the second within-domain pairing less well, albeit still significantly. Finally, the experiment in this thesis (see Part 2 of the previous chapter) showed that familiarity supported associative recognition of both within- and between-domain pairs and, in absolute terms, supported between-domain pairs more strongly. When the level of familiarity was calculated as a proportion of associative recognition, then the familiarity contribution did not differ between within- and between-domain associations.
These findings confirm the potential for familiarity to support associative memories under some circumstances. In fact, they suggest that it can do so, to varying degrees, under the majority of circumstances. This finding must be controversial, given the multitude of studies that demonstrate a predominant contribution of recollection to, if not as a necessity for, associative recognition performance (for example Turriziani, Fadda, Caltagirone, & Carlesimo, 2004). Indeed, associative memory tests in several forms (including, for example, source memory tasks) typically have been used as a measure of recollection. It is necessary to consider why it might be the case that these divergent results have appeared.

If one assumes that familiarity cannot support recognition, one is likely to interpret any finding that seems to imply that familiarity can successfully support associative recognition as somehow confounded by methodological issues. Of course, there are methodological issues surrounding any behavioural study. Any behavioural study must make a number of assumptions, each of which will affect the subsequent results, and it is reasonable to question the appropriateness of these assumptions. While a common methodology (the familiarity-only procedure) has been employed in the three previously related studies, Harlow and colleagues (2010) also employed an ROC analysis that resulted in similar findings. Flaws in experimental design may also lead results to be misleading and, although the peer review process seeks to avoid obvious confounds and inappropriate conclusions, few studies can test all possible interpretations within one design. Many further behavioural studies will be needed in order to confirm that familiarity successfully supports associative recognition of many kinds of association, and these studies will need to be replicated in many laboratories before the case becomes completely convincing. However, the appropriate way to investigate the deeper claim of the Domain Dichotomy view requires investigation of the neural bases of familiarity memory, particularly in the medial temporal lobe structures, and this is best investigated in humans with functional neuroimaging (fMRI).
The Domain Dichotomy theory is based upon clinical findings and a cytoarchitectural model of the medial temporal lobes. It should be possible to explore which structures activate or deactivate during the learning of within- and between-domain pairs and when familiarity is being used on its own to recognise the resultant associative memories. Predictions about medial temporal lobe activation changes that relate to familiarity can be made, and these are in addition to behavioural claims about how familiarity should support particular types of association. Certain types of stimuli should show common activations in neocortical regions. According to the Domain Dichotomy view, the stimuli with the greatest neocortical activation overlap should form within-domain pairs when studied together; those that produce the most dissimilar neocortical activations with the least overlap, should form between-domain pairs. The former should show convergent BOLD changes in the perirhinal cortex and possibly in the parahippocampal cortex whereas the latter will only produce convergent BOLD response changes in the hippocampus. In other words, in an associative task, where familiarity is successfully contributing to associative recognition, neocortical structures lower in the medial temporal lobe hierarchy, such as the perirhinal cortex and the parahippocampal cortex, should show BOLD response changes whereas hippocampal activity changes should not be found. If, as it has been shown in this thesis, associative recognition of many different types of pairs is supported by a feeling of familiarity, then there should be considerable overlap between the areas not only of neocortex that represent the related pairs, but also of perirhinal and possibly parahippocampal cortex that are postulated to process familiarity for the pairs as items but also as associates. A thorough exploration of whether the mnemonic processing of multiple different types of stimuli overlaps significantly, especially in the medial temporal lobes structures that are lower in the processing hierarchy, such as the perirhinal and parahippocampal cortices, might shed light on which kinds of association the deeper version of the Domain Dichotomy theory should claim will support associative familiarity.
Previous studies have looked at regions of activity related to familiarity memory for objects using a continuous recognition paradigm. For example, Johnson and colleagues (2008) explored changes in medial temporal lobe activations when items were repeated several times. Although their study neither trained participants concerning the differences between recollection and familiarity, nor required responses other than an indication of whether they thought the item had been previously presented, the use of very short durations of stimulus presentation (500ms) was thought to have forced the predominant use of familiarity, as recollection is associated with longer and more effortful retrieval in stark contrast to the fast and automatic nature of familiarity (Yonelinas, 2002b). This assumption is well founded despite some evidence to the contrary, which has found that recollection responses are quicker than those relying on familiarity under non-speeded conditions (Dewhurst, Holmes, Brandt, & Dean, 2006). Recent studies have found evidence supporting the traditional view that, when speeded responses are required, familiarity is predominantly used to support rapid decisions (Sauvage, Beer, & Eichenbaum, 2010; Verde & Perfect, 2011). Also, the Johnson and colleagues study used the brief presentation not only during retrieval but also (because it used a continuous recognition task) during encoding, and it seems likely that this alone would have minimised elaborative encoding that would have led to subsequent recollection, i.e., there would have been minimal subsequent recollection even if more retrieval time had been allowed. Johnson and colleagues reported that the effects they found were not influenced by the type of stimulus studied; they used a mixture of concrete words and colour pictures of objects. They found BOLD response activity changed in several regions that showed reduced activity for old items irrespective of the number of presentations (bilateral medial hippocampus and left posterior parahippocampal cortex), and other regions which showed graded reductions as the number of repetitions increased (adjacent regions of right lateral hippocampus and left parahippocampal cortex). Generally, however, they found that no medial temporal lobe regions were more active for repetitions of stimuli than when encountering novel items. Extra-medial temporal lobe results were not reported.
While the previous study represents an example of a continuous recognition experiment, continuous recognition studies are comparatively rare when compared to traditional studies that use distinct study and test phases. However, the advantage of the continuous recognition paradigm is that it allows for the efficient presentation of a large number of stimuli and for the elapsing of a fixed passage of time between the first and second presentations. There has also been the suggestion that continuous recognition studies might better reflect ‘experiences of daily life’ (Suzuki, Johnson, & Rugg, 2011). As in the case of Johnson and colleagues (2008), other studies have employed the technique in order to examine changes in brain activity across multiple presentations. Yassa and Stark conducted a study comparing multiple repetitions of previously (non-experimental) familiar pictures, pre-trained images and novel images (Yassa & Stark, 2008). They found three distinct patterns of activity including monotonic decreases in activity in the parahippocampal cortex and the anterior perirhinal cortex while there were monotonic increases in the posterior perirhinal cortex as the stimuli were repeated. Unfortunately, this continuous recognition study cannot shed much light on familiarity processes, as distinct from recognition processes, because no special manipulations were used to isolate and identify familiarity for previous occurrences from possible recollection.

The fMRI experiment forming the basis of this chapter sought to examine which regions of the brain showed overlapping patterns of activation for a variety of stimulus types, including those used in the behavioural test of associative recognition memory used in the Bastin and colleagues (2010) study, Harlow and colleagues (2010) study and the Experiment in Part 2 of Chapter 2. This continuous recognition study included the presentation of six distinct categories of visual stimuli. In order to achieve its aims the experiment allowed for only two presentations of each stimulus. Unlike previous continuous recognition studies, the focus of this experiment lay in identifying which regions of activity were common across the six types of stimulus in a typical novel-vs.-studied paradigm, as opposed to focussing on the changes produced by multiple
repetitions. Here, the focus was on identifying the overlap produced by familiarity for stimuli in different categories. To this end, the familiarity-only procedure was employed so as to allow the analysis of those brain regions specifically recruited in judging that a stimulus has been previously experienced where there are no specific recollections to report (Montaldi, et al., 2006). By training participants not to try to recollect stimulus-related study context details that diagnosed that a stimulus had been presented already, effortful recollection processes at retrieval were successfully minimised or even eliminated, isolating those regions of the brain involved in experiencing familiarity for the stimulus. Furthermore, by removing the emphasis on recollecting additional information at test about the study episode, encoding of the stimuli would be focussed upon the same familiarity judgement (or novelty judgement, assuming that novelty represents the opposite end of a continuum of ‘oldness’ from high familiarity) that participants would be using at test. The domain dichotomy view fundamentally claims that, if there is going to be a good level of successful familiarity for a given kind of association, then its components must be mnemonically processed in the perirhinal cortex (or possibly the parahippocampal cortex). If this is true, then familiarity for the components of any such association will produce overlapping changes in perirhinal cortex (and possibly parahippocampal cortex) activity. It is a subsidiary expectation that stimuli for which this is the case will activate closely adjacent or overlapping neocortical regions, although this is not central to the hypothesis.

A common source of overlap in a neocortical structure could help to explain the finding that both within- and between-domain pairs are able to be supported by familiarity. These effects may be apparent at either study or retrieval (first or second presentation). It may be the case, as has been proposed for neurons mediating item familiarity in the perirhinal cortex, that the overlap will be shown by common regions of activation greater at study than at test (repetition suppression). It is unlikely that the current study will be able to ascertain precisely what the degree of overlap is for the neural effects produced by familiarity for the different stimulus
classes within specific medial temporal lobe structures, such as the perirhinal cortex. The ability of the current study to make very fine grain discriminations is limited because it uses whole brain scanning that involves using comparatively large voxel sizes (compared with high resolution fMRI scanning that focuses solely on the medial temporal lobes) and also does not use other advanced methods of scanning of the medial temporal lobes (such as dual echo techniques) to avoid susceptibility artefacts (Poser & Norris, 2009; Poser, Versluis, Hoogduin, & Norris, 2006). As with the behavioural examinations of the Domain Dichotomy theory, many further studies will be needed to fully identify the neural substrates of associative familiarity. If, however, familiarity effects for different categories of stimuli are found in overlapping perirhinal or parahippocampal cortical regions, this would possibly be consistent with the deeper claim of the theory and would provide a strong starting point for further explorations of such substrates.

**Method**

**Participants**

Twenty right-handed volunteers (twelve women; mean age 22.9, (SD 3.6; range 19-32) gave informed consent and underwent a medical examination before taking part in the study, which had received local ethics committee approval. All the participants were in good health and were screened to ensure that they had no neurological or psychiatric problems.
**Stimulus Materials**

204 images were used throughout the study. These comprised 34 images from each of 6 different categories of stimulus. These categories were ‘abstract art’, ‘animals’, ‘faces’, ‘scenes’, ‘tools’ and ‘written words’. These were drawn from the same pools of stimuli as had been used in the previous continuous associative recognition experiment (See Chapter 2). Of the 34 stimuli in each stimulus category, 4 were chosen at random as ‘dummy stimuli’ (see procedure) while 30 were target stimuli (stimuli for which new and old responses were analysed).

**Experimental Procedure**

Participants were instructed to ask themselves for each presentation of a stimulus, “has this stimulus been presented before?”. The task was conducted using the familiarity only task, a modified remember/know familiarity procedure (Montaldi, et al., 2006). Prior to taking part in the experiment, participants were extensively trained on the differences between familiarity and recollection. The instructions lasted for approximately 10 minutes (depending on the participant’s progress in understanding the instructions) and involved several stages. These were as follows:

- Written descriptions of familiarity and recollection;
- Experimenter–prompted explanation of those instructions from the participant;
- Feedback given to correct errors in comprehension;
- Verbal description, with examples of familiarity and recollection generally;
- Verbal instructions of the specific task and of familiarity and recollection as they relate to the task;
- An opportunity to ask the experimenter any questions and for further clarification to be given if necessary.
Throughout the verbal component of the instructions close attention was paid to the participant’s comments and reactions in order to ensure understanding at every stage. Participants were instructed to focus on how familiar a given stimulus was and not to try to recollect. However, should they recollect something, they were trained to indicate this with the appropriate response. There were three potential responses: new (not presented before); old (had been presented before, based solely on a feeling of familiarity); and recollected (had been presented before, based on a specific and inadvertent recollection). ‘New’ responses were made with the first finger of the left hand, ‘old’ responses with the first finger of the right hand and ‘recollected’ responses with the middle finger of the right hand. The left and right hands were counterbalanced across participants. Participants were instructed to respond as quickly and as accurately as possible: they were also instructed that, should they find themselves responding ‘old’ and then subsequently inadvertently recollecting something about the stimulus, they should adapt their response speed in order to enable them to indicate that they had unintentionally recollected the stimulus.

Stimuli were presented using E-Prime software (www.pstnet.com). The order of the stimuli was randomly produced for each participant conforming to the following criteria. The experiment consisted of a single run with each stimulus presented twice. An average of 80 (SD 12) stimuli were presented between the first and second presentation of each item. Each stimulus was presented for 2500ms with a fixation crosshair, presented for 500ms, separating each stimulus presentation. Two stimuli from the same stimulus category were presented sequentially (one after the other) except where one of the two stimuli was a dummy stimulus. Two dummy stimuli from each category were presented and repeated within the first 40 target items. These were included in order to produce ‘old’ responses when the majority of the target stimuli were new. A further two dummy stimuli were presented once in the last 40 items of the run so as to provide ‘new’ responses when the majority of the target items were old. The responses for these
dummy stimuli were excluded from the analysis of memory performance but were included within the design matrix. Randomly presented throughout the experiment were 60 fixation crosshairs which were presented for the duration of a stimulus presentation (2500ms). These trials were incorporated to act as baseline trials.

**fMRI Image Acquisition**

Scanning was conducted using a 3T MRI scanner (Philips, Achieva). The blood oxygenation level dependent (BOLD) response was measured using a gradient echo-planar (EPI) sequence. A total of 726 (363 per session) volumes were acquired at retrieval using a repetition time (TR) of 2500ms and an echo time (TE) of 3500ms. The voxel size was 2.5 x 2.5 x 3.5 mm and comprised a matrix of 96x96 with 40 slices. The slices were aligned parallel to the AC-PC line. A whole brain scan was conducted with ascending acquisition. In addition, T1-weighted images (matrix size: 256x256, number of slices: 180, voxel size 1mm isotropic) were collected for each participant in order to provide high resolution images to align the functional data. Head motion was minimised during scanning by the use of foam supports. Ear defenders were used to protect participants from scanning noise and images were displayed using a front projection screen viewed via a mirror mounted on the head coil.

All data were processed and analysed using SPM8 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, University College London, London, UK; http://www.fil.ion.ucl.ac.uk/spm/). A six-parameter rigid body transformation was used to realign the EPI data to the first image and reslice them using sinc interpolation in space. All images were spatially normalised to the Montreal Neurological Institute (MNI) EPI template.
brain and were smoothed with an isotropic 5mm full width, half maximum (FWHM) Gaussian kernel.

All subsequent procedures described employed the default SPM8 settings unless otherwise stated. The data, having been preprocessed, were analysed using the general linear model on a voxel-by-voxel basis. Canonical Hemodynamic Responses were assumed. For each participant, two separate, though very similar, models were used. In the first model (the exclusion analysis), response categories consisted of correct rejections (first presentation “new”), false alarms (first presentation “old”), hits (second presentation “old”) and misses (second presentation “new”), for each of the six categories of stimulus. In addition, four more variables were created to include the recollection responses (irrespective of stimulus category), the dummy stimuli, “no response” responses, and the interstimulus fixations (the implicit baseline) respectively. Finally, in addition to the above variables, those correct rejections which were subsequently recollected were modelled separately. In the second model, (the inclusions analysis), the same model was used as above with the exception that those items which were correctly rejected at their first presentation but were subsequently recollected inadvertently during their second presentation were included with the other correct rejections. The additional response category in the exclusions condition, excluded from the results activations particularly related to encoding that resulted in subsequent inadvertent recollections. First level analysis consisted of a series of t-test comparisons for each participant producing the contrast images that was used in the second level analysis.

For each category of stimulus, the first presentation was compared with the second presentation and the second presentation compared with the first. A High-Pass filter of 128 seconds was employed. Thresholds of \( P<0.001 \) uncorrected were employed for the first presentation greater than second presentation (with a focus on exploring the predicted medial
temporal lobe activations) while $P<0.05$ FEC was employed for the second presentation greater than first presentation. Conjunction analyses were conducted using the Global method as described below (Chumbley & Friston, 2009).

**Results**

**Behavioural Results**

Each new item trial was categorised as a correct rejection if correctly identified as ‘new’ during the first presentation or as a false alarm if incorrectly identified as ‘old’. The second presentation events were classified as hits if correctly identified as ‘old’ based on familiarity and misses if they were incorrectly identified as ‘new’.

The average number of recollections (excluding false recollections) across participants and stimulus categories was 10.44 (SD 9.08), or 5.8 percent of total responses. The average total number of false recollections across participants and stimulus categories was 0.6 (SD 1.3), or 0.33 percent of total responses. Owing to the absolute nature of event-related fMRI (each item can only be coded once), familiarity performance values were calculated using the exclusivity assumption.

The mean proportion of responses which were missed (nonresponses) was 0.02 (SD 0.04).
### Table 7. Details of memory performance based upon familiarity and recollection hit rates and false alarm rates.

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Recollection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hit Rate</td>
<td>False Alarm Rate</td>
</tr>
<tr>
<td>Abstract Art</td>
<td>0.51 (0.16)</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>Animals</td>
<td>0.80 (0.12)</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>Faces</td>
<td>0.70 (0.18)</td>
<td>0.24 (0.18)</td>
</tr>
<tr>
<td>Scenes</td>
<td>0.64 (0.19)</td>
<td>0.09 (0.08)</td>
</tr>
<tr>
<td>Tools</td>
<td>0.86 (0.14)</td>
<td>0.18 (0.10)</td>
</tr>
<tr>
<td>Words</td>
<td>0.68 (0.17)</td>
<td>0.06 (0.05)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.70 (0.12)</td>
<td>0.11 (0.08)</td>
</tr>
</tbody>
</table>

A repeated measures ANOVA was conducted in order to assess whether there was a significant difference between familiarity memory for the different types of stimulus. There was a significant difference in familiarity memory across the different types of stimulus $F_{(5,85)} = 14.276$, $p<.001$. Bonferroni post hoc analysis showed significant differences ($p<0.05$) between the different stimulus types, with each category significantly different from at least one other category (see Figure 15). Beginning with those categories of stimulus with the lower levels of familiarity memory performance, the ‘face’ category was significantly lower than the ‘animal’, ‘tool’, and ‘word’ categories. The ‘abstract art’ category saw significantly lower performance than that of the ‘animal’, ‘tool’ and ‘word’ categories. ‘Scenes’ also showed significantly lower familiarity memory performance than did the ‘animals’ or ‘tools’ categories.
Figure 15.

Familiarity Memory Performance (Hit rates-False Alarm rates) for the six categories of stimulus. Error bars represent standard deviations. Joining bars represent significant differences in memory performance P<0.05.

fMRI Results

For the purposes of the fMRI analysis, responses were categorised in a similar fashion to those used in the behavioural analysis. However, two analyses were conducted with the following difference: in the first analysis, correct rejections (identifying stimuli as ‘new’ on their first presentation), which subsequently resulted in an inadvertent recollection response were excluded (the exclusion analysis) and, in the second analysis, all correct rejections were included whatever the subsequent response was given to their second appearance (the inclusion analysis). A more detailed description of the difference between these two type of analysis is outlined later in the results section. It is very likely that stimuli that were subsequently recollected will have been encoded more strongly, or with additional involvement of recollection-supporting structures such as the hippocampus. Any stimulus event that either led to subsequent recollection or itself was recollected was excluded from the analysis in order to enable the activation effects of
familiarity alone to be examined. As shown in the behavioural results, the number of inadvertent recollections was very small and it is not clear that their exclusion would produce significantly different patterns of activation. Conducting both analyses allows this comparison, but the focus is on those results produced in the exclusion analysis. Analysis was conducted in order to examine whether common regions of the brain are involved in supporting familiarity for the six categories of stimulus using a conjunction analysis.

A note on conjunction analyses

There remains debate regarding how best to conduct conjunction analyses, with two distinct options available in SPM8. These are the Conj’n and Global methods. A full discussion of the two approaches is beyond the scope of this chapter. Nonetheless, a brief mention of the two types of analysis concerning the method adopted in this analysis is included here in an attempt to clarify the results produced. The Global approach is the older of the two approaches and has been employed, as is the case in this analysis, by many studies. The Conj’n method reflects the conclusions of other researchers who consider the Global approach to be excessively lenient (Nichols, 2005).

Both techniques seek to find overlapping areas of activation between different conditions within an fMRI study. They differ in their approach to this task. The Conj’n method only considers those voxels which were significant at a standard level in the global analysis of each condition to represent a significant conjunction. This means that, for a voxel to appear significant in the conjunction analysis, it must be significant according to a given threshold for each component contrast. The Global method, on the other hand, looks for consistent activations across conditions allowing experiments to infer a conjunction of one or more effects.
(Chumbley & Friston, 2009). This approach does not require that any voxel be significantly active in each and every contrast according to a given threshold. In other words, it allows that significance levels for some individual contrasts may be somewhat weaker, provided they overlap with the more significant individual contrasts.

The Conj'n approach cannot be faulted for seeking to impose a high standard of statistical probability except that it is somewhat unclear what the point of doing a conjunction analysis at all actually is. As with all scientific endeavour, where results are always dependent on probability, there is a danger that, by relying upon too stringent a criterion in an effort to avoid type 1 errors, type 2 errors emerge (a serious problem given the relative lack of sensitivity of fMRI), particularly in medial temporal lobe structures, such as the perirhinal cortex. The danger with the Global approach is that too strong conclusions may be drawn from a lack of understanding of what a significant voxel represents under its assumptions. Should a voxel be found to be significant using a Global conjunction, the results inform us that there is a conjunction of effects of two or more of the contrasts in this location, and that the remaining contrasts show weaker effects at the overlapping site.

The goal of this study was to identify those regions that are likely to be involved with the familiarity processing of a variety of stimuli. It is not necessary to conclude that there is exact overlap between the various categories of stimuli in any given location. It is unlikely that a study could have sufficient number of stimuli, and thus power, to establish this with as many distinct types of stimulus as tested here. With this more general aim (and with an understanding of the implications and limitations of a Global conjunction) the following results were found.
Conjunction Analysis

As mentioned above, the following results listed here were produced using the exclusion analysis (see Analysis section in Method).

A global conjunction of the six types of stimulus was conducted, looking at patterns of consistent activation across the varied types of stimulus. Two sets of analysis were conducted, exploring which structures showed activations at study, (1>2, first presentation more active than second), and which activated more at test (2>1, second presentation more active than first). These will be explored in turn.

1>2

Few regions of the brain were more significantly active at study than at test. It is interesting to note that a bilateral medial frontal effect was found corresponding to BA 10 $P<0.001$ uncorrected. In addition to these frontal effects two significant clusters were found in the medial temporal lobes. These were located in the right anterior hippocampus ($x = 12, y = -4.5, z = -18.5$) and in the posterior parahippocampal cortex ($x = -35.5, y = -39.5, z = -8$) $P<0.001$ uncorrected. This parahippocampal activation was very close to a previously found parahippocampal activation ($-32,-42,-11$) using a continuous recognition paradigm (Cohn, Moscovitch, Lahat, & McAndrews, 2009). When the global threshold was reduced to $P<0.05$ uncorrected, a single voxel was found to be significant in the right anterior medial temporal lobe ($x = 27, y = -7, z = -9$). The presence of this significantly activated voxel suggests that a perirhinal cortex activation may be present, albeit slightly less significant than the $P<0.001$ level of uncorrected significance, in the whole brain analysis. Perirhinal cortex effects have been found consistently in studies of item recognition, with increased activity at study and with progressive
reductions in activation representing a putative neural representation of familiarity memory (Brown & Aggleton, 2001). This research is derived predominantly from intracranial recordings of non-human primates, which have shown selective reductions in the firing of certain perirhinal neurons after repeated presentations of specific object stimuli (Brown & Xiang, 1998). Given that the previous finding was both a single voxel, and only present at a reduced threshold for significance, this activation is not considered sufficient evidence of perirhinal activations alone and further evidence was sought. Henson, Cansino, Herron, Robb, and Rugg, (2003) conducted a meta-analysis of four distinct fMRI studies that used three different types of stimulus including words, faces and pictures. They produced a centre of mass for the common region with the coordinates 22,-6,-28. Using a small volume correction analysis (sphere, radius 10mm) at these coordinates enabled a more stringent analysis to be conducted to confirm the presence of the perirhinal cortex activation. A two voxel right perirhinal cortex cluster emerged from this analysis at the coordinates x = 27, y = -9.5, z = -29, P<0.05 FEC.

<table>
<thead>
<tr>
<th>Side</th>
<th>Region</th>
<th>Voxels</th>
<th>~BA</th>
<th>MNI</th>
<th>Z-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Right</td>
<td>Medial Frontal Gyrus</td>
<td>14</td>
<td>10</td>
<td>2</td>
<td>63</td>
</tr>
<tr>
<td>Left</td>
<td>Medial Frontal Gyrus</td>
<td>10</td>
<td>-10.5</td>
<td>58</td>
<td>-8</td>
</tr>
<tr>
<td>Left</td>
<td>Parahippocampal Cortex</td>
<td>8</td>
<td>37</td>
<td>-35.5</td>
<td>-39.5</td>
</tr>
<tr>
<td>Right</td>
<td>Hippocampus</td>
<td>8</td>
<td>34</td>
<td>12</td>
<td>-4.5</td>
</tr>
</tbody>
</table>

Table 8. Brain regions demonstrating greater activity at Study (first presentation greater than second presentation), P<0.001 Uncorrected.

Some of the important activations are illustrated in the Figure 16 on the following page.
1>2 First Presentation greater than Second Presentation

Right Perirhinal Cortex
27,-9.5,-29

Right Hippocampal Activation
12,-4.5,-18.5

Left Parahippocampal Cortex
-35.5,-39.5,-8

Right Medial Frontal Gyrus
2,63,-4.5

2>1 Second Presentation greater than First Presentation

Left Medial Frontal Gyrus
-33,55.5,9.5

Left Inferior Parietal Lobe
-40.5,-52,41

Left Middle Temporal Gyrus
-60.5,-49.5,2.5

Left Caudate & Thalamus
-10.5,15.5,2.5

Figure 16. Graphical representation of brain activations for the 1>2 and 2>1 analyses.
While the 1>2 contrast produced few activations, with those found located either in the frontal lobes or medial temporal lobes, the 2>1 contrast produced a range of clusters spread throughout the neocortex. However, no medial temporal lobe regions were found to be more active at test than they had been at study. The regions found in the 2>1 condition were often lateralised to the left hemisphere. They included large clusters in the frontal lobes and parietal lobes, in the left and right precuneus, the left and right caudate, left thalamus, as well as a cluster encompassing the posterior cingulate/retrosplenial cortex region, and another in the left superior and middle temporal gyri (see Table 9).

<table>
<thead>
<tr>
<th>Side</th>
<th>Region</th>
<th>Voxels</th>
<th>-BA</th>
<th>MNI</th>
<th>Z-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>Inferior Frontal Gyrus</td>
<td>99</td>
<td>47</td>
<td>-50.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Left</td>
<td>Superior Frontal Gyrus</td>
<td>344</td>
<td>10</td>
<td>-33</td>
<td>55.5</td>
</tr>
<tr>
<td>Left</td>
<td>Middle Frontal Gyrus</td>
<td>10</td>
<td></td>
<td>-25.5</td>
<td>53</td>
</tr>
<tr>
<td>Left</td>
<td>Inferior Parietal Lobe</td>
<td>234</td>
<td>40</td>
<td>-40.5</td>
<td>-52</td>
</tr>
<tr>
<td>Left</td>
<td>Inferior Parietal Lobe</td>
<td>40</td>
<td></td>
<td>-45.5</td>
<td>-44.5</td>
</tr>
<tr>
<td>Left</td>
<td>Precuneus</td>
<td>7</td>
<td></td>
<td>-28</td>
<td>-54.5</td>
</tr>
<tr>
<td>Left</td>
<td>Precuneus</td>
<td>87</td>
<td>7</td>
<td>-3</td>
<td>-69.5</td>
</tr>
<tr>
<td>Right</td>
<td>Precuneus</td>
<td>7</td>
<td></td>
<td>7</td>
<td>-72</td>
</tr>
<tr>
<td>Left</td>
<td>Precuneus</td>
<td>7</td>
<td></td>
<td>-13</td>
<td>-64.5</td>
</tr>
<tr>
<td>Left</td>
<td>Caudate</td>
<td>51</td>
<td></td>
<td></td>
<td>-10.5</td>
</tr>
<tr>
<td>Left</td>
<td>Thalamus</td>
<td></td>
<td></td>
<td></td>
<td>-15.5</td>
</tr>
<tr>
<td></td>
<td>Posterior</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cingulate/Retrosplenial Cortex</td>
<td>10</td>
<td>23</td>
<td>-0.5</td>
<td>-29.5</td>
</tr>
<tr>
<td>Left</td>
<td>Superior Temporal Gyrus</td>
<td>2</td>
<td>39</td>
<td>-53</td>
<td>-54.5</td>
</tr>
<tr>
<td>Right</td>
<td>Caudate</td>
<td>2</td>
<td></td>
<td></td>
<td>14.5</td>
</tr>
<tr>
<td>Left</td>
<td>Middle Temporal Gyrus</td>
<td>2</td>
<td>22</td>
<td>-60.5</td>
<td>-49.5</td>
</tr>
</tbody>
</table>

Table 9. Brain regions demonstrating greater activity at Test (second presentation greater than first presentation), P<0.05 FEC.
1>2 and 2>1

There was a marked difference in activations between those regions that were more activated at study than at test and vice versa. This is an unusual pattern of activity to find but is consistent with other continuous recognition tasks. A series of studies employing the continuous recognition paradigm with very short stimulus exposure time (500ms), forcing the use of familiarity as the principal memory process, found consistent deactivations of medial temporal lobe memory structures at test (Johnson, et al., 2008; Suzuki, et al., 2011). However, these results were largely limited to the medial temporal lobes by either the use of high resolution scanning or masking. The whole brain analysis from the current experiment has highlighted a large number of extra-medial temporal lobe activations, which are greater at test than at study. This finding is in contrast to another continuous recognition study that found medial temporal lobe activations for test, although this study included recollection responses, illustrating the differences in activation that can be found when comparing familiarity and recollection processing (Yassa & Stark, 2008). It seems likely that medial temporal lobe activations related to recollection effects in the Yassa and Stark (2008) study were minimized in the current study and other continuous recognition studies, for example, Suzuki and colleagues (2011).

Variations in hippocampal activity as a function of the inclusion and exclusion analysis

As detailed above, an analysis was also conducted comparing hippocampal activations when stimuli which resulted in subsequent inadvertent recollections were included. This inclusion analysis did not contain any recollection responses. Instead it reflects small changes in the categorising of the responses made to the first presentation of the items. In the exclusion condition, correctly rejected items (first presentation) which were subsequently recollected as old (at second presentation) were removed from the correct rejection variable for their stimulus
category in the design matrix and were instead pooled under the subsequent recollection variable. In this inclusion condition, all items presented for the first time, which were correctly identified as new, were coded as correct rejections for their respective stimulus categories irrespective of the response made at second presentation. This categorisation took place on an item by item basis. See Figure 17 for graphical representation. No analysis of recollection responses (second presentation) was conducted owing to the limited number of recollection responses.
**Exclusion Analysis**

<table>
<thead>
<tr>
<th>First Presentation</th>
<th>Second Presentation</th>
<th>Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Rejection</td>
<td>Miss</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Hit (Familiarity response)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Hit (Recollection response)</td>
<td>No</td>
</tr>
</tbody>
</table>

**Inclusion Analysis**

<table>
<thead>
<tr>
<th>First Presentation</th>
<th>Second Presentation</th>
<th>Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Rejection</td>
<td>Miss</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Hit (Familiarity response)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Hit (Recollection response)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Figure 17.**

A graphical representation of the possible responses a participant may make to a given item, which was correctly rejected at study, when it is presented for a second time and whether it is included in the correct rejection pool for that stimulus type under the two types of response.

In the inclusion analysis, small numerical differences were found for the previously identified hippocampal cluster. The peak was located in the same place, while the number of voxels increased by two and there was a z-value increase from 4.07 to 4.58. This effect was very slightly magnified when a more lenient threshold of $P<0.005$ uncorrected was used, with an increase in the cluster size from 19 to 22 voxels. No additional significant hippocampal activations were found in the inclusion analysis at the original threshold value of $P<0.001$ uncorrected. Whilst these differences are evident they do not reflect a significant or substantial difference in the pattern of activation. This finding suggests that, in the absence of excluding those items which would have been recollected had effort been made at test (impossible given the nature of the familiarity only procedure), the small number of more automatic recollections made during the experiment produced very little difference to the resulting hippocampal activations.
Discussion

This study sought to identify the sites, within and outside the medial temporal lobes, that are activated together when familiarity is experienced for stimuli that fall within six different categories of visual stimulus. The aim was to find out to what degree, and where, these kinds of visual stimulus are processed mnemonically in overlapping regions of the medial temporal cortex. If overlap in mnemonic processing occurs in the perirhinal or parahippocampal cortices, the Domain Dichotomy theory predicts that stimuli that fall within these different categories and produce these overlapping effects should, if the conditions are right (for example, encoding that links components directly together) be bound together to form associative memory representations that will support associative familiarity. If stimuli do not show significant overlap in these structures but only converge in the hippocampus, then recognition of any association will have to be supported by recollection because associative familiarity will not be found. Strictly speaking, faces and abstract picture stimuli are in different domains according to the hypothesis because face and abstract picture stimuli fall in different categories. However, the more basic question that the Domain Dichotomy hypothesis raises is whether such between-category stimuli share sufficient common features for them to be processed mnemonically within the neocortical regions of the medial temporal lobes, so as to allow their binding together into associative memory representations that support familiarity well. In other words, the deeper version of the theory allows the possibility that more than within-domain associations are processed within the perirhinal cortex and/or possibly within the parahippocampal cortex. Nonetheless, even if conjunction analysis reveals interesting areas of overlap within the medial temporal lobes when familiarity is experienced for different stimuli in different categories of information, care must be taken in interpreting the results.
A continuous recognition paradigm was used that employed familiarity only instructions in order to isolate those regions responsible for processing familiarity memory. Conjunction analysis showed that a number of significant regions were consistently either deactivated or activated when familiarity memory was experienced for stimuli in the different visual categories in both the 1>2 and 2>1 comparison conditions, although the level of significance for some of the categories may have been somewhat lower as the method of conjunction analysis used allows. These regions included the classical medial temporal lobe structures thought to be involved for recognition memory, such as the perirhinal and parahippocampal cortices and the hippocampus; for these regions, familiarity was associated with consistent deactivations relative to the first time presentation of a stimulus. This deactivation pattern for familiarity responses fits with earlier findings (for example, Montaldi et al., 2006). Outside the medial temporal lobes, activations in the frontal and parietal regions were found, as well as in other non-neocortical as well as neocortical, structures, such as the caudate and other temporal lobe regions.

These extra medial temporal lobe regions included parietal and retrosplenial activations which have been associated in the past with recollection-type responses (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000). These might be considered unusual given the familiarity-only procedure employed. However, they have also been found to be modulated by the strength of familiarity responses (Montaldi, et al., 2006). The posterior superior parietal region, which shows consistent activity in a number of recognition memory studies, has been proposed as playing a role in the monitoring of internal memory states (Wagner, Shannon, Kahn, & Buckner, 2005). It is plausible that this effect would be considerable in a familiarity only task where participants must focus on the nature of their memory for any given item, monitoring whether or not they have experienced inadvertent recollection. Alternatively, as parts of these regions also respond selectively to familiarity, they may be involved with monitoring, or even generating, familiarity signals or, perhaps, in interpreting what they mean. The retrosplenial
cortex is thought to comprise part of a core network that includes the hippocampus, which is engaged in processes associated with memory but not necessarily limited to memory (Vann et al., 2009). While this is the case, its activation within the context of this familiarity only continuous recognition paradigm suggests a role in familiarity processing, in the absence of recollection. This would be consistent with the independence dual processing hypothesis according to which recollection and familiarity memory share some kinds of processing that may be performed, for example, by the retrosplenial cortex, but they do not share other kinds of processing and these are mediated by distinct brain structures, such as the hippocampus (recollection) and perirhinal cortex (item/object familiarity memory).

The unique demands of a familiarity only continuous recognition task provide a challenge when cross-study comparisons are to be made. Few studies have employed procedures that isolate familiarity processes, or diverge from the standard approach of distinct study and test phases. Nonetheless, when comparisons are made with the existing studies, striking similarities emerge. In concert with those other studies using continuous recognition, there was a striking difference in the localisation of brain activations, with medial temporal lobe sites showing greater activation at study (i.e., greater activation for novel than repeated stimuli that were recognised or, as in the case of the current study, just found familiar) while extra-medial temporal regions activated at test (Johnson, et al., 2008; Suzuki, et al., 2011). In general, the sites of retrieval deactivation and activation seemed to be distinct. This pattern of activity may be specific to those experiments employing a continuous recognition paradigm whilst incorporating a manipulation to isolate familiarity processing. This is best explained by the emphasis that continuous recognition studies place on detecting and encoding new items (Johnson, et al., 2008). It seems probable that when items are identified as new rather than studied or old, there is an automatic tendency to encode them more deeply and so increase the likelihood of producing a memory that will subsequently be capable of supporting recollection.
The Domain Dichotomy view, along with other dual process accounts, predicts that the hippocampus is activated when encoding produces such recollection-supporting memories. In the study that has been reported in this chapter, the use of the familiarity only procedure would mean that only automatically generated recollections should have been produced whereas recollections dependent on effort should be minimal. Therefore, the procedure does not allow the full potential amount of subsequent recollection to be determined. It seems very probable that hippocampal activity was greater at study for correctly rejected stimuli in the current fMRI experiment because detection of novelty often triggered elaborative encoding that led to subsequent recollection. However, the successful use of the familiarity only procedure meant that only some of the potential subsequent recollection was detected in the form of involuntary recollection. No attempt was made to recollect whether stimuli had been presented previously in the continuous recognition task and this effortful recollection would probably have constituted most of the subsequent recollection potential if the fMRI familiarity only task worked as well as it did in the Chapter 2 experiment. This likelihood is supported by the 1>2 hippocampal effect being only marginally smaller in the exclusion analysis than in the inclusion analysis where correct rejections that led to involuntary recollections were counted in with the other correct rejections: presumably most of the recollections that might have been shown were not because their retrieval would have required effort. Nevertheless, the 1>2 hippocampal effect related to elaborative encoding that leads to later potential for recollection is usually overshadowed by a greater increase for those stimuli that are recollected at test, both through automatic and effortful retrieval processes. This conclusion is supported by the finding that if recollection is directly measured under conditions that facilitated recollection, then hippocampal activations at test were greater than those at study, even in a continuous recognition paradigm (Suzuki, et al., 2011). In other words, whether the hippocampal 1>2 or 2>1 effect dominates depends on the balance
between the amount of elaborative encoding that successfully produces later recollection potential at encoding and the amount of actual recollection at test.

It might be argued that the hippocampal activity at study suggests a greater contribution of recollection type processing than should occur, given the apparent success of the familiarity only procedure at reducing inadvertent recollections. It should be noted that, whilst the goal of the familiarity only procedure is to reduce recollection responses (by removing effortful recollections in order to provide sufficient numbers of familiarity responses for a sufficiently powerful analysis), the procedure does not completely eliminate recollection processing. When the three varying assumptions of familiarity inclusion in recollection responses (exclusivity, independence and redundancy) are calculated, there is a consistent finding of statistical differences in the amount of familiarity (Bastin et al., 2009; Harlow et al.; 2010; Part 2 of Chapter 2). This simply relates, however, to the difficulty in measuring the level of memory discrimination that is driven by familiarity and does not affect the interpretation of the current fMRI study’s results. The recollection responses are those produced inadvertently and are, most likely, the result of strong levels of recollection producing processing at study. Finally, as already indicated, the procedure makes it impossible to identify those recollection responses that would have been produced had effortful retrieval methods been encouraged at test. It is possible that participants may have processed stimuli they felt were novel slightly differently because they knew that they should not try subsequently to recollect any stimuli; however, this requirement seems very unlikely to influence encoding and, particularly so, if novelty detection triggers elaborative encoding automatically rather than effortfully, i.e. the encoding may have been minimally subject to voluntary control where the participant consciously chose to employ a certain strategy.
The regions identified in this study show a remarkable consistency with those regions identified in the only other fMRI study to employ the familiarity only procedure (Montaldi, et al., 2006). Many of the same extra-medial temporal lobe regions in which familiarity activations were linearly modulated as a function of confidence, strength and reaction time to respond that were identified in the Montaldi and colleagues’ paper were also found in the 2>1 condition of the current study. In other words, there are a number of brain regions that Montaldi and colleagues’ study found were activated by familiarity versus novelty for scenes that in the current study were found not only to be activated by scenes, but also by visual words, tool pictures, animal pictures, abstract pictures and faces. This suggests that there is a common network of structures involved in processing familiarity signals in the absence of recollection for a wide range of visual stimuli that carry what appear to be very different kinds of information. These stimuli fell in a number of different categories and so, if that had been associated together, would have formed between-domain rather than within-domain associations according to the superficial interpretation of the original version of the Domain Dichotomy view. In particular, the finding that perirhinal cortex was activated in the conjunction analysis of the 1>2 comparison supports the hypothesis that all the various between-domain associations that could be formed between these categories as well as the within-domain associations would be mnemonically processed in this cortex and lead to memories that are well supported by associative familiarity as the findings in chapter 2 suggest.

It might be argued by proponents of the Conj’n approach to conjunction analysis that this result might be present because a Global conjunction was employed. Global conjunctions merely prove that there is a consistent activation in a given area of more than one condition. The current study used five categories of stimulus as well as scenes, but it was only the scene stimuli that were similarly used by Montaldi and colleagues (2006). If it were the case, however, that these ‘conjunction’ activations were produced by the scene stimuli in the absence of a real overlap with the familiarity activations produced by the stimuli from the other five categories,
numerous other regions involved in the processing of those other stimulus types should have been detected. This was not the case. Another factor supporting the conclusion that the activations found in this study reflect common regions of activation for several stimulus types is that the specific sites of activation, while overlapping closely in their structural locations, differ in their peak activations. The size of the clusters in the conjunction analysis of the present study also exceed those for the Montaldi and colleagues (2006) study. This is in line with the hypothesis that, while a given structure supports familiarity processing, the specific part of that structure involved may vary depending upon the type of stimulus being processed.

In conclusion, this study explored the degree of overlap of medial temporal lobe and extra-medial temporal lobe familiarity deactivations or activations for visual stimuli of several different categories in a continuous recognition experiment employing the familiarity only procedure. Familiarity activations outside the medial temporal lobes were found to overlap in frontal, parietal, temporal, retrosplenial and other subcortical sites, such as the caudate and thalamus, as indicated by a global conjunction analysis. These findings looked robust and, furthermore, they closely overlapped with scene familiarity-related activations reported by Montaldi and colleagues with the familiarity only procedure (although this other study also used ratings of familiarity strength and found that the overlapping structures were ‘upregulated’ by increases in familiarity strength). Results were consistent with previous studies that have used similar designs. Large areas of overlap were detected in regions with theoretical links to processing of item recognition memory. These structures may form a network involved in processing of familiarity memory for items. This study may form the basis for future studies that can try to identify to what extent familiarity-processing of different categories of stimulus is carried out in overlapping medial temporal lobe and extra-medial temporal lobe regions, so as to help determine where within- and between-domain categories are processed in the medial temporal lobes and elsewhere in the brain in order to find out whether the deeper level of the
Domain Dichotomy theory is correct. In particular, it will need to be determined what activity in these various brain regions reflects about the different kinds of processing, needed for familiarity, that seems to be common between a variety of kinds of stimuli.

Finally, and of most relevance to this theory, are the familiarity deactivations shown in the current fMRI study. The perirhinal cortex overlap between stimuli from the six categories of stimuli is closely aligned with the effects reported by Henson and colleagues (2003) for familiarity deactivations with three similar stimulus categories. It could well be, therefore, that stimuli from all six categories are processed in overlapping regions of the perirhinal cortex. This suggests that it is likely that the perirhinal cortex should, under certain conditions, be able to bind stimuli from any combination of these categories to create inter-‘item’ or intra-‘item’ associative representations that are good at supporting associative familiarity but very poor at supporting recollection. The overlapping deactivations found in the parahippocampal cortex and hippocampus are harder to interpret, although they are very similar to the effects found by Rugg and his colleagues in a series of continuous recognition studies (e.g., Suzuki et al., 2011). Most likely, these effects are not related to familiarity retrieval but to the effects of the elaborate encoding of new stimuli that are correctly perceived as new so as to produce memories that are able to support subsequent recollection (even if they did not do so within the familiarity only procedure used in the experiment described in this chapter). Such effects are known to be associated with hippocampal and parahippocampal cortex activations that are linked to successful elaborative encoding (see Suzuki et al., 2011). Future work will need to examine this plausible possibility more formally and rigorously.
Chapter 4: General Conclusions and Future Work

The Domain Dichotomy theory represents a novel and exciting theoretical paradigm which has the potential to broaden our understanding of the memory processes supporting associative recognition. If found to be correct, even in part, revisions will need to be made to the majority of theories seeking to explain memory for relationships between distinct items. Nonetheless, it is a relatively new theory, albeit drawn from evidence collected from several studies in the last two decades and it has received little exploration and testing. In the work presented here, methods of testing the Domain Dichotomy theory were explored and preliminary tests of the theory were conducted.

In Chapter 2, several pilot studies were conducted in order to assess the best methods of testing the claims of the Domain Dichotomy theory. In addition, a behavioural experiment testing associative recognition was also run that directly measured the extent of the contribution of familiarity for recognition memory of different kinds of association. In Chapter 3, an fMRI study was completed exploring the overlap in regions modulated by familiarity for a range of different kinds of stimulus. The general conclusions of these tests will be discussed in the subsequent sections, with emphasis on possibilities for future work.

Chapter 2: The behavioural tests.

Part 1.

Central to the Domain Dichotomy theory is the concept of domain as a variable affecting how memory for associations is formed and supported (Mayes, et al., 2007). If two
items to be remembered are of the same domain, then the encoded information representing them should converge at a lower point in the medial temporal lobe hierarchy in such structures as the perirhinal or parahippocampal cortices (Montaldi & Mayes, 2010). These structures, which support familiarity processes, have the potential to form a memory representation of an association that mainly supports familiarity. However, if two items are of different domains, then the encoded information representing them should converge only later in the hierarchy, within the hippocampus, and so that a different kind of associative memory representation only capable of supporting recollection should be created.

Intuitively, between-domain pairs can be regarded as comprising two kinds of paired items or components between which there are substantial semantic and perceptual differences, whereas within-domain pairs can be regarded as having very much smaller semantic and perceptual differences between their paired stimuli. This has led to experimenters using simple categories of stimuli to represent within- and between-domain examples. Within-domain pairs have been pairs of stimuli taken from the same category and between-domain pairs have had their component items drawn from distinct categories, such as animals and vehicles or tools and meaningful sounds. While this is convenient, and may be correct, the concept of domain as used by the Domain Dichotomy theory is, at the deeper level of the theory, not defined in terms of such semantic categories. It is based, instead, upon the idea of varying degrees of neural overlap in processing semantic and perceptual representations of the component stimuli particularly within the hierarchy of brain structures in the medial temporal lobes. The clearest example of distinct neural processing of stimuli comes from contrasting visually and aurally presented stimuli that are processed within clearly distinct neocortical regions, which are likely to project to different medial temporal lobe regions that do not strongly interact.
Sound stimuli have been employed rarely in recognition memory experiments, although there have been studies exploring the effect of stimulus modality reinstatement (Nyberg, Habib, McIntosh, & Tulving, 2000). The first pilot study, outlined in Chapter 2, sought to determine whether it was feasible to prepare auditory stimuli for use in associative recognition studies. Certain difficulties were encountered, predominantly caused by an inherent vagueness in the auditory stimuli tested; not all environmental sounds were recognised and, when they were recognised, they were not always correctly identified. Future work might seek to further prepare, and test possible meaningful environmental sounds so as to ensure ease of recognition so that their semantic content would be well controlled. The pilot was unable to fully achieve this, which indicates that, although this goal may be reachable, it will be harder to achieve that initially anticipated. Particular effort will be needed to produce high quality audio stimuli that are presented in such a manner as to ensure the reduction of distractor noises. This would include the use of a high quality workflow from recording the stimuli, throughout editing the files and finally at presentation. This may incorporate professional grade recording equipment, editing software and headphones or speakers capable of faithfully reproducing the stimuli.

Theories of associative recognition memory commonly assume that associative memory formation is independent of memory for the component items. One way in which item memory is likely to significantly affect memory for more than one item is if the component items are themselves easier, or harder, to remember. In order to control for these effects in subsequent associative recognition memory experiments, a continuous recognition pilot study was run with several distinct kinds of stimulus. This study also served as a pilot for future continuous recognition experiments, including the fMRI study described in chapter 3 of this thesis. Although there were significant differences in memory performance between some of the types of stimuli, such as between Animal Pictures (which were remembered best) and Spoken Words (which were remembered worst), recognition memory performance in the worst remembered
category was not less than 75% of that of the highest category. Therefore, encouragingly this suggested that multiple categories of stimulus could be paired in different combinations without necessarily confounding subsequent associative recognition memory effects with item recognition. In addition to the data on recognition memory performance, key information, such as the correct spacing of repetitions in a continuous experiment, was obtained. Future work could use a more standard ‘study and test phase’ model in order to compare item memory for different stimulus types (or use a refined continuous recognition study paradigm), improved with the information gained in this pilot, to enhance the understanding of how memory performance for different types of stimuli varies when study and test conditions are controlled.

Having developed a set of different types of auditory stimuli and having established broadly similar memory performance for items across categories, it was necessary to investigate how auditory stimuli could be studied in an associative task. The temporal nature of auditory stimuli makes simultaneous presentation difficult at best: consequently a sequential approach was used. Within the auditory associative task, three combinations were used including within-domain pairs of ‘environmental sounds’ and ‘random noises’ and a between-domain pairing of the two. The pairs of sounds themselves were clearly indicated and a single presentation of each sound pair was made. Participants also completed a conventional (simultaneous presentation of stimuli) animal picture within-domain pair test so as to compare performance with a standard measure of visual stimulus associative memory. Associative recognition memory performance for the auditory pairs as a whole, and for each type of selective pairing, was not significantly different from zero. The same participants performed well in the conventional animal pair task.

Poor item memory for the environmental sounds should not have represented a confound in this task as, in the continuous recognition study mentioned above test of item memory, performance was not significantly lower than that of the animal picture stimulus class.
However, the item memory of the abstract sounds was not assessed directly so it is not possible to be certain of how item memory for those stimuli might have affected associative recognition performance for pairs including these stimuli. It might be noted that the abstract art (visual stimuli) as tested in the fMRI Experiment in Chapter 3 were the second worse recognised category of stimulus (only outperforming faces) suggesting that perhaps abstract stimuli are challenging to remember. Nonetheless, those results were still well above chance despite being produced within a familiarity only paradigm which would not suggest an automatic floor effect for abstract stimuli. Future work might try to fully map item recognition memory performance for both environmental sounds and random noises to control for this potential effect of item memory. In addition, visual stimuli might be presented sequentially to match procedures with the auditory stimuli allowing straightforward comparisons between performance in visual and auditory associative recognition tasks.

The auditory associative task highlighted the difficulties both for an experimenter, in trying to design an experiment which includes auditory stimuli yet matches conventional visual stimulus experiments, and for participants, in trying to learn auditory associations. Although, given the pilot nature of the research, the results were drawn from a relatively small number of participants the results could not have been clearer. Participants who were able to perform very well on a conventional animal pair associative recognition memory task were unable to remember pairs of auditory stimuli above chance. Future work should seek to refine presentation techniques for auditory stimuli and to discover under what conditions it might be reasonable to expect participants to perform without ceiling or floor effects. Nonetheless, even with refinements, it may not be possible to test pairs of auditory stimuli in a way which is directly comparable to visual stimuli. Instead, it may be possible successfully to use between-domain pairs of aural and visual stimuli as this would conform to the requirement of simultaneous presentation. Recognition of within-domain pairs of auditory stimuli and within-domain pairs of
visual stimuli might be compared in a less biased way by presenting pairs in rapid succession rather than simultaneously.

The three pilot studies in Chapter 2 sought to examine methodological issues related to testing the Domain Dichotomy theory. A central theme of these three studies was the question of how best to construct and test the theory which makes explicit predictions based on stimulus domains. At this stage, it is not possible to make clear statements regarding what constitutes a within- or between-domain beyond the previous acknowledgements that, when paired together, visual and auditory stimuli are likely to be a good example of a between-domain pair not just in the sense of being in different categories, but in the deeper sense of it being likely that they are processed in non-overlapping parts of the medial temporal lobes that minimally interact. In addition, while two visual items might be considered to constitute a within-domain pairing by the above definition, this does not discount the commonly held assumption of within- or between-“stimulus category” pairs serving to determine within- or between-domain categories. Stimuli can vary perceptually and semantically. A systematic assessment of perceptual and conceptual similarity, presumably carried out in parallel but not simultaneously, would make a meaningful contribution to our understanding of what constitutes a ‘domain’. This enterprise would, however, be very difficult owing to the number of variables to measure and the need to compare across large numbers of individual stimuli from each potential category. For instance, the word “cow” and a picture of a cow are, presumably, highly semantically similar despite intuitively being grouped under the categories of pictures of animals and written words. However, they differ far more perceptually than the word “cow” and the word “bow” (as in the projectile weapon), which are visually very similar but, in turn, differ semantically despite being grouped together as words.

If auditory stimuli were to be included in any given assessment the difficulty is only increased. If the words “cow” and “bow” were presented as spoken words their perceptual
similarity would be much reduced. With this example, two stimuli, the words “cow” and “bow” can be perceptually similar or perceptually dissimilar depending on the method of presentation. These examples may not be truly representative of the varying similarity of potential stimuli. It may be the case that, given sufficient numbers of stimuli and a complex method of sorting responses, participants could provide accurate measures of similarity for different kinds of stimulus. However, it is not obvious that the conscious assessments of stimulus similarity are sufficient accurately to determine the degree of neural overlap in the neocortex or medial temporal lobes required to define a pair of stimuli as within- or between-domain. It is based on the intuitive assumption that the more similar two stimuli are subjectively perceived to be the more likely it is that they will be processed in closely adjacent and interacting neural sites. However, the direct evidence for the assumption is not yet compelling and, even if true, under certain conditions, very dissimilar stimuli may be processed in the same neural region. Furthermore, depending on the brain region, certain kinds of similarity may matter, but others not when it comes to overlapping and interactive processing. The problems with determining the similarity of stimuli in order confidently to label some pairs as within-domain and others as between-domain, does not mean that the task should not be attempted.

**Part 2.**

The final behavioural study sought to test the Domain Dichotomy theory directly by contrasting recognition memory performance for different kinds of associative pairs. Having found substantial difficulties with the use of auditory stimuli it was decided only to use visual categories. Many different kinds of stimulus were used with participants completing either four within-, or four between-domain pairs. In addition, participants were randomly assigned to either a standard recognition paradigm, or the familiarity-only procedure, a modified remember/know
paradigm, which sought to emphasise responses based on familiarity. Memory performance in the familiarity-only condition was significantly above chance for all but one of the pairs of stimuli. In contrast to the predictions of the Domain Dichotomy theory, those pairs classed as between-domain (in the sense that paired stimuli belonged in different semantic categories) had higher absolute levels of performance in the familiarity condition than those classed as within-domain. However, when familiarity was calculated as a proportion of the standard recognition score no differences were found, irrespective of whether a pair was a within- or between-domain association. Whether an absolute or proportional familiarity measure is held to be most theoretically appropriate, the results clearly support the findings by other researchers that familiarity can support associative recognition memory not only for within-modality associations, but also for within-domain associations of at least some kinds (Bastin, et al., 2010; Harlow, et al., 2010).

These results can be explained in a number of different ways. The first is that a large proportion of the pairs of items in all the conditions were unitised and that this contributed to familiarity being able to support the associations. The second is that the associative recognition of the within-domain pairs were truly being supported by associative familiarity for the link between two paired items (i.e., inter-item associations), whilst the between-domain pairs were supported by item familiarity following unitisation. These two explanations both seek to explain the results by resorting to unitisation as the critical factor, albeit in a different way. Unfortunately, it is not agreed how best to measure unitisation or when it occurs. Nonetheless, while it could have occurred, typically, pre-existing associations need to have been present or special instructions need to have been given to generate significant amounts of unitisation, even then it is probably that many trials will be needed rather than merely one or two. Furthermore, none of these conditions was present in this study.
There are two possible objective methods which might, in the future, help to identify when unitisation has occurred. These rely upon the properties different properties of unitised and non-unitised (inter-item associative) memories. The first method involves measurements of reaction times while the second is measurement of recognition memory for the component items of potentially unitised pairs and non-unitised pairs. Reaction times might be faster when identifying unitised pairs (similar to that of identifying items) than inter-item associations. Additionally, familiarity memory for the component items of pairs which have been unitised may be lower than that of the component items joined by inter-item associations. These two methods have significant methodological issues which will need to be resolved before they can be effectively implemented. However, studies such as that completed in Part 2 of Chapter 2 could be expanded to include some tests of reaction times or component recognition to check for the presence of unitisation in either or both of the domain conditions.

The third possibility to explain the results of this experiment is that the surface interpretation of the Domain Dichotomy view is wrong. This interpretation postulates that, after rapid learning, recognition within-domain associations, defined as groupings of stimuli all belonging to the same category, is well supported by associative familiarity whereas recognition of between-domain associations, defined as groupings of items falling in different categories, under the same conditions, is much more poorly supported by associative familiarity. This is shown to be wrong by the findings of the experiment reported in Chapter 2 of this thesis and also by Harlow, MacKenzie and Donaldson’s (2010) study. However, the deeper interpretation of the Domain Dichotomy view is that such within-domain stimuli converge on the perirhinal cortex (and possibly the parahippocampal cortex) where they are either mnemonically processed so as to form unitized representations or, under different conditions and less automatically, so as to form inter-item associations. In both cases, the grouped stimuli will be well supported by associative familiarity. The results of the experiment reported in this chapter could mean that
even between-domain stimuli converge in the perirhinal/parahippocampal cortices where associative memory representations are created that subsequently support associative familiarity memory. It is, therefore, important to determine whether familiarity for different categories of stimuli affects activity in overlapping sites in the perirhinal cortex and possibly in the parahippocampal cortex. This theoretical need naturally leads into the final fMRI study.

**Chapter 3.**

The fMRI study detailed in Chapter 3 sought to measure the degree of overlap in neural structures that mediate item familiarity memory for different kinds of stimulus. With information derived from the continuous recognition pilot in Chapter 2, a continuous recognition paradigm with two presentations (one repetition) was employed, presenting images from six different kinds of stimuli. As with the associative recognition experiment discussed previously, a familiarity-only paradigm was chosen in order to maximise familiarity responses. A conjunction analysis was conducted so as to ascertain which areas within both the medial temporal lobes and other whole brain regions showed common patterns of activation. The key findings were, *inter alia*, that only a few medial temporal lobe activations were found in the contrast 1>2, which indicated that familiarity for all six categories of stimuli was related to reduced, and overlapping activation in those sites. On the other hand, several extra-medial temporal lobe areas activated significantly in the 2>1 contrast, which indicated that familiarity for all six categories of stimuli was related to increased and overlapping activation at those sites. No significant medial temporal lobe effects were found in the 2>1 contrast. This effect is consistent with other continuous recognition studies and may be a product of the continuous recognition paradigm, perhaps in conjunction with the side effect of using the familiarity-only procedure which is to reduce the number of detected recollected responses. The activations themselves were consistent with previous studies,
with a common perirhinal encoding-related activation at study (and subsequent deactivation at test), as well as remarkable correspondence (in the extra-medial temporal lobe activations) with the Montaldi and colleagues (2006) study that had employed the familiarity-only paradigm. Of potential concern was the finding that the hippocampus was significantly activated at study relative to second presentations of stimuli that were found to be familiar. However, it seems likely that this finding was related to the fact that encoding of many stimuli might have led to it being possible with effort to subsequently recollect them. But this recollection would not have been detected because it would have required effort and the use of the familiarity-only procedure prevents this. When effortful retrieval does not occur because it is effortful no retrieval activation of the hippocampus or parahippocampal cortex will occur, but there will be an encoding activation of these sites if they are active during the construction of recollection-supporting memories of the six different categories of stimuli. In summary, the fMRI study identified several areas of the brain (both within and outside the medial temporal lobes) which seem to be shared between multiple stimulus categories, including many of those used in the associative memory experiment in Chapter 2. It is reasonable to assume that these activity changes reflect different familiarity processes at different brain sites that are common to all six categories of stimuli.

The findings in the fMRI study lend support to the third explanation for the results in the behavioural test of associative recognition memory. If, as suggested by the results, these categories of stimulus share common regions of processing that critically include the perirhinal cortex, the deeper interpretation of the Domain Dichotomy view that quite a few different categories of stimuli converge on that structure for mnemonic processing. Furthermore, the experiment in Chapter 2 indicates that with between-domain combinations of some of the stimuli scanned familiarity-supporting associations can be fairly rapidly formed. Nevertheless, it remains to be determined whether the production of associative familiarity for or the display of
associative familiarity for these stimuli when combined into between-domain associations produces activity changes that are relatively selective to the perirhinal cortex within the medial temporal lobes. Such experiments will need to control for the contaminating effects of encodings that would only become apparent later if effort is made to retrieve them.

The fMRI study related in Chapter 3 serves as a strong starting point for a full exploration of the Domain Dichotomy theory using fMRI. It supports the findings of behavioural studies, which have shown memory for associations supported solely by familiarity, by indicating regions of neural overlap (within and outside the medial temporal lobes) during familiarity memory for different kinds of stimulus while participants were not experiencing recollection, consistent with the predictions of the Domain Dichotomy theory. Nonetheless, it is clear that, building upon the findings made here, further evidence will need to be gathered. A remember/know version of the current study could be conducted. This would allow a clear contrast of brain regions, which are modulated by either familiarity or recollection, without the confound that is discussed at the end of the previous paragraph that occurs when encoding produces memories that would only lead to subsequent recollection if effort is applied at retrieval (use of the standard remember/know procedure that encourages effortful recollection achieves this).

In addition, future studies should strive to identify three specific points. First, it should seek to confirm and expand upon the findings above by exploring the degree of overlap in neural activations for different kinds of stimuli in memory tests when participants are only using familiarity. This might include the use of larger categories of stimulus with more exemplars in each. It might also include auditory stimuli, perhaps through the use of sparse fMRI scanning or specialist headphones for presentation of auditory stimuli within the environment of an fMRI scanner. Crucially, for the purposes of testing the Domain Dichotomy theory, a more fine
grained analysis of the medial temporal lobes must be conducted. This is in order to examine, as best as imaging technology currently allows, the degree of overlap of the different kinds of stimuli within different medial temporal lobe structures such as the perirhinal cortex where signal distortion and loss are found as a result of susceptibility artefacts. To do this advanced scanning techniques, such as high spatial resolution scanning and dual-echo techniques (which reduces susceptibility problems), should be employed.

High resolution scanning is not an unusual technique and has several advantages (Dudukovic, Preston, Archie, Glover, & Wagner, 2010; Duncan, Ketz, Inati, & Davachi, 2012; Preston et al., 2009). High resolution scanning employs smaller voxels (for instance 1.5mm³), which produce a more specific localisation (important for exploring the Domain Dichotomy theory) and can potentially reduce signal distortion (Kirwan & Stark, 2007). However, high resolution scanning can result in a reduced signal to noise ratio, reduced power and necessitates a reduced coverage of the brain. When the medial temporal lobes are scanned with high resolution imaging it is not possible to investigate extra-medial temporal lobe activations. Another area where improved scanning can be employed to test the Domain Dichotomy theory is through the use of dual-echo methods. This technique employs multiple echo-times during scanning. The use of a shorter echo-time (for instance 11ms) results in less power than traditional echo-times (around 32ms), but produces less signal dropout and distortion that often results from the sharp transition between media being imaged (brain tissue, air, etc.) found in the region of the medial temporal lobes (Poser & Norris, 2009; Poser, et al., 2006).

While these techniques described above would facilitate better exploration of stimulus/brain region activation during item memory tasks, ultimately tests must be made of associative familiarity directly and they would be well employed during these experiments as well. The key test will be the exploration of which regions of the medial temporal lobes support the
associative familiarity memory found in the behavioural tasks discussed above. It is critical that, in any such experiment, responses are carefully controlled (by excellent participant directions, instruction, and debriefing) so that those pairs which are rejected (not considered to be old based upon a feeling of familiarity) are not accompanied by recollection (recalling to reject), or that pairs which are missed are not accompanied by some form of non-diagnostic recollection. Either, or both, of these types of responses are likely to modulate activity in the hippocampus, thereby confounding any contrasts in which they occur.

Given that currently a range of different kinds of stimulus pairs, within- and between-domain, seem to be supported by associative familiarity, numerous comparisons will need to be made between potential types of pairs. It is unclear at this stage, and unsupported by any neuroimaging evidence, whether or not the neural substrates of associative familiarity memory are similar to, or different from, those of item familiarity memory. Contrasts will have to be made between successful instances of associative recognition memory with unconfounded misses (no item recollection) or correct rejections (not based on recall to reject) to ensure an clean contrast (see previous paragraph for details on controlling responses).

Finally, the information garnered from these functional studies must be used to design associative memory experiments in which different kinds of associations are tested, where the component items are selected that most clearly do or do not converge in the perirhinal cortex (and possibly the parahippocampal cortex). With the selection of pairs based upon hard neuroimaging data it should be possible finally to establish whether familiarity can support memory for associations for pairs according to the predictions of the Domain Dichotomy theory or not. If this line of testing is successfully completed it might be interesting to explore whether familiarity support for associations extends to different kinds of association, such as temporal associations.
Conclusion

Throughout this thesis the Domain Dichotomy theory has been discussed as a theory that makes unique predictions about how familiarity should support associative memory. Initially, this thesis explored how the theory might be tested. In the early parts, it has explored the use of different kinds of stimuli, identifying advantages and problems associated with them. It has sought to test the theory directly using a behavioural paradigm but produced results without clear explanations. Finally, an fMRI study was conducted the results of which provide a possible explanation (areas of common neural overlap for several different kinds of stimuli) explaining why the aforementioned behavioural associative recognition study (and other studies like it) produce the results they do. At this point it is possible to reflect upon the general findings of the thesis within a wider context. The Domain Dichotomy theory represents one of a newer strain of theories that seek to describe medial temporal lobe function with regards to recognition memory. The other is the BIC model. While the Domain Dichotomy theory proposes that associative familiarity for pairs is likely to be supported by the perirhinal cortex, owing to its ability to pattern complete. The BIC model maintains, in line with more traditional dual process views, that associative memories (relational in the terminology of the BIC model) must be supported by the hippocampus and be dependent on recollection.

This thesis cannot, and did not attempt to, answer the key question of whether or not the Domain Dichotomy theory is correct in its entirety. Instead, it represents an investigation as to how best to test the theory and provides some preliminary findings, which hint at the conclusions that may be drawn in the future. The pilot work outlined in Part 1 of Chapter 2 highlights the difficulty that will be involved in designing tests of the Domain Dichotomy theory, although it may provide inspiration for others to take forward and develop their own methods of testing. In contrast, Part 2 of Chapter 2 provides, at this point, further evidence in support of a
Domain Dichotomy-like theory. The results are inconsistent with the superficial interpretation of the Domain Dichotomy theory whether absolute or proportional measures of familiarity are used. Nonetheless, the findings are not consistent with the BIC model either.

Given that the Domain Dichotomy theory suggests that, under some circumstances, familiarity should support associative recognition, it seems more likely that the, perhaps modified, Domain Dichotomy theory is correct. It may even be the case that the Domain Dichotomy theory does not need to be modified dramatically as its predictions are based upon neural overlap, rather than intuitions about where in the medial temporal lobes different categories of stimuli converge for mnemonic processing, and these strong predictions have yet to be tested. The BIC model is, at present, unable to account for the findings in this and other studies, apart from claiming, implausibly, that all of the studied pairs were unitised and it will be interesting to see how the theory develops to accommodate them. The fMRI study detailed in Chapter 3 is, again, not itself a test of the Domain Dichotomy theory. It does, however, provide evidence for neural overlap of several different kinds of stimulus within the medial temporal lobes. This is consistent with the predictions of the Domain Dichotomy theory although the findings are not inconsistent with the BIC model.

It is too early to proclaim the Domain Dichotomy theory as correct in its present modified form. A body of evidence is, nonetheless, growing which confirms at least the spirit of its predictions, such that greater investigation is warranted. With the confirmation of associative familiarity from Part 2 of Chapter 2, the evidence for the predicted neural overlap of different types of stimulus from Chapter 3 and the constructive recommendations for how to explore the theory produced by Part 1 of Chapter 2, it should be possible to explore the Domain Dichotomy theory further in the coming years.
References


Murray, E. A., & Wise, S. P. (2004). What, if anything, is the medial temporal lobe, and how can the amygdala be part of it if there is no such thing? *Neurobiology of Learning and Memory*, 82(3), 178-198.


