EXPLORING THE INTERACTION BETWEEN WORKING MEMORY AND LONG-TERM MEMORY: EVIDENCE FOR THE WORKSPACE MODEL

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DECLARATION

Exploring the interaction between working memory and long-term memory: Evidence for the workspace model

I declare that this thesis is of my own composition, and that the material contained within describes my own work. It has not been submitted for any other degree or professional qualification.

All quotations have been distinguished by quotation marks and the sources of information acknowledged.

Marian van der Meulen
February, 2008

ABSTRACT

There is a large range of models of working memory, each with different scopes and emphases. Current interest focuses strongly on the interaction of working memory with long-term memory, as it has become clear that models of working memory alone are incapable of capturing some of our complex cognitive abilities. Most models have contrasting views on how this interaction is implemented. In this thesis, three classes of models are defined, each proposing a different type of interaction. The first model proposes that working memory acts as a *gateway* for perceptual input on its way to long-term memory. In the *unitary* model, working memory is seen as comprising the activated portion of long-term memory. The *workspace* model views working memory as a workspace that is separate from, and deals with the activated contents of long-term memory. The main aim of this thesis was to address the differences between these three models experimentally.

Experiments 1 – 7 employed a dual-task paradigm to investigate the effects of irrelevant visual input on visuo-spatial working memory tasks. Two main findings emerged: (1) maintenance of images in working memory was largely insensitive to the effects of concurrent perceptual input; (2) mental imagery was susceptible to interference from irrelevant visual input. This interference effect was selective, as demonstrated by a lack of disruption of imagery by other secondary tasks. Experiment 8 further tested the three models by investigating implicit processing of visual information by neglect patients. It was found that implicit processing is mediated by the activation of long-term memory, in the absence of a conscious representation in working memory.

These results together converge to support the workspace model, and suggest a view in which perceptual input activates the contents of long-term memory, prior to these activated representations being made available in a functionally separate working memory system for further processing. The gateway model and unitary model are unable to accommodate all findings. The implications of these results for existing theories about working memory are discussed.

CONTENTS

CHAPTER 1

Models of the Interaction between Working Memory and Long-Term Memory

1.1 INTRODUCTION

Working memory (WM) is a system for temporarily storing and manipulating information required to carry out complex cognitive tasks such as learning, reasoning, and comprehension. The field of working memory has made significant progress during the past three decades, which is reflected in the large range of models of WM, each with different scopes and emphases (for reviews see Logie & D'Esposito, 2007; Miyake & Shah, 1999; Osaka, Logie & D'Esposito, 2007). One important aspect on which some models have radically different views is the flow of information in the memory system, and related to this, the interaction between WM and Long-Term Memory (LTM). Current interest focuses strongly on this link between WM and LTM, as researchers are more and more realising that there is a stronger interaction between WM and LTM than often assumed. It has become clear that models of WM alone are incapable of capturing some of our complex cognitive abilities, and researchers from different areas have now stressed the importance of understanding the relationship of WM with LTM (see e.g. Baddeley, 2000, 2002; Burgess & Hitch, 2005; Jones, Gobet, & Pine, in press; Ranganath & Blumenfeld, 2005; Woodman & Chun, 2006). In reviewing the models of WM in the edited book by Miyake and Shah (1999), Kintsch, Healy, Hegarty, Pennington, and Salthouse (1999) concluded that most models explicitly acknowledge a close relationship between WM and LTM, regardless of whether they emphasise the distinction or the continuity between the two constructs. However, the question remains as to exactly how this interaction is implemented and how information processing works from perception to LTM and WM. Models of memory that do make an assumption about the interaction between WM and LTM can be subdivided into three broad classes, on the basis of the nature of this proposed interaction. The first type of model is the gateway model, in which WM acts as a gateway between perceptual input and LTM. In the unitary model, WM is seen as comprising the activated areas of LTM. The third model views WM as a workspace that is separate from and deals with the activated contents of LTM. These three classes of models thus propose fundamentally different interactions between WM and LTM. This thesis aimed to address the differences between these models empirically, using two different approaches, one using the methods of experimental psychology, and one using the methods of cognitive neuropsychology.

The present chapter will describe the three classes of models in detail, discussing their origins, supporting findings and arguments, and their assumptions. Also some important representative examples from each class of models will be reviewed. A number of fundamental complications of the gateway and unitary model will be outlined in detail in Sections 1.4.1 and 1.4.2 respectively. The last section (1.5) in this chapter discusses how the three models can be investigated experimentally. This section describes the methodology employed in Experiments 1 – 7 (Chapters 2 – 8) of this thesis. These experiments used dual-task techniques to compare the models by testing their predictions about interference in visual working memory tasks. The next chapter (Chapter 9) in this thesis reviews the literature on implicit semantic processing of visual perceptual information in patients with hemispatial perceptual neglect. Accounts of the three models for implicit semantic processing will be discussed. Experiment 8 (Chapter 10) adopted this cognitive neuropsychology approach to contrast the three models of the interaction between working memory and long-term memory. The last chapter (Chapter 11) provides a general discussion of the main findings of this thesis, and discusses the implications of these findings in a wider context.

1.2 THE GATEWAY MODEL

1.2.1 Separating short- and long-term memory

The first type of model originates from early information processing models of memory that assumed a structural distinction between Short-Term Memory (STM) and Long-Term Memory (LTM), and considered STM as a *gateway* between perceptual input and LTM. Before the rise of these models it was commonly assumed that memory was a single system, with no distinction between short and long-term storage. This started to change in the 1950's and 60's when evidence started to accumulate for the existence of separate short and long-term memory stores. Some of the key findings leading to the suggestion of two separate memory systems concerned mechanisms of forgetting, the primacy and recency effect, different memory codes, and neuropsychological data. These initial observations (and some more recent views on each one) will be discussed in detail below.

Different mechanisms of forgetting

Over a century ago, Müller and Pilzecker (1900) reported one of the first demonstrations of forgetting due to interference. They found that participants were less likely to recall a memory item if in the interval the retrieval cue that was used to test that item had become associated with another memory. Later in the twentieth century, researchers started to find evidence for another mechanism of forgetting, namely decay. It was demonstrated that small amounts of information were rapidly forgotten unless actively rehearsed. A paradigm that was long used as evidence for decay as a mechanism of forgetting was the Brown-Peterson paradigm, after Brown (1958) and Peterson and Peterson (1959). In this paradigm, participants are presented with three items (usually consonants) and are asked to recall all three items in the correct order. During the retention interval between presentation and recall, participants engage in a distractor task (backwards counting) to prevent rehearsal. Stimuli in the distractor task are different from the to-be-retained items. Under these circumstances, participants forget very rapidly, and this was interpreted in terms of trace decay. Peterson and Peterson (1959) argued that the forgetting in their experiment could not be explained by interference, because the numbers of the backwards counting were sufficiently different from the letters to be remembered. These results thus seemed to suggest the need to assume two separate memory systems; a short-term system in which forgetting results from decay, and a long-term system in which forgetting results from interference.

This argument for separate memory systems was later abandoned, however, on the basis of subsequent research demonstrating that the forgetting in the Brown-Peterson paradigm could also be explained in terms of interference. Keppel and Underwood (1962) replicated the Peterson and Peterson task, keeping the time delay between presentation and recall of items constant (e.g. 12 seconds). They analysed their data by trial number, and found that as the number of trials increased, recall decreased. This result suggested that the previous trials were a source of proactive interference (see also Lewandowsky, Duncan & Brown, 2004; Nairne, 2002; Neath & Brown, 2006). Although mechanisms of forgetting are no longer taken as evidence for separate short- and long-term memory systems, there is still a lot of debate about the role of interference and decay in forgetting (e.g. Altmann & Gray, 2002; Anderson, 2003; Cowan, 2003; Nairne, 2002; Page & Norris, 1998).

The primacy and recency effect

Another observation that was initially taken as evidence for distinct STM and LTM systems was the presence of separable components in free recall. In a free recall task participants are presented with a list of unrelated words and asked to recall as many as possible in any order. When recall is immediate, participants show better memory for the first few words of the list (primacy effect) and for the last few words (recency effect). When there is a brief filled delay before recall, the recency effect disappears while memory for the first few words in the list remains relatively unaffected. The primacy effect appears to be independently affected by other variables, such as the familiarity and rate of presentation of the items in the list, the age of the participant and the requirement to perform some other concurrent task (for a review see e.g. Neath & Surprenant, 2003). Traditionally, these observations were explained by assuming two different memory stores. The first items of the list have had more time to be rehearsed, and are thus more likely to have been transferred to a LTM store. Rehearsal is more difficult as the number of items in the list increases, and therefore transfer to LTM becomes less efficient. The most recent items of the list are remembered better because they are still in STM, whereas the earlier items from the list have been replaced by these more recent items. When there is a brief delay, the last few items from the list have also disappeared from STM due to decay, explaining the disappearance of the recency effect. These results thus seemed to support the distinction between two memory stores (e.g. Atkinson & Shiffrin, 1968; Postman & Phillips, 1965).

This explanation of the primacy and recency effect has later been abandoned after subsequent research has shown that there are problems, for example, with interpreting the recency effect as a phenomenon uniquely associated with short-term memory. The recency effect is still observed when a concurrent six-digit memory load must be maintained throughout presentation of the list. Maintaining the digits would take up most of the capacity of the short-term store (e.g. Baddeley & Hitch, 1977). Moreover, the recency effect appeared to not be restricted to immediate recall tasks, but also occurs for longer term memories in real-life situations (e.g. Baddeley & Hitch, 1977; da Costa Pinto & Baddeley, 1991). Baddeley and Hitch (1977), for example, asked rugby players to recall the names of the teams they had played during the many weeks of the Rugby Union competition, and found better recall of the most recent teams. A long-term recency effect has also been demonstrated in experimental laboratory settings, for example in the continuous distractor paradigm (e.g. Bjork & Whitten, 1974; Tzeng, 1973). This is an immediate free recall task in which a distractor task is included before and after every item in the list. A recency effect is still found, even though there is a delay between presentation and recall due to the distractor task. The recency effect was thus observed in situations in which a short-term store could not possibly have played a role (see also Capitani, Della Sala, Logie, & Spinnler, 1992; Tan & Ward, 2000). Additionally, there were problems with interpreting the primacy effect in terms of rehearsal and storage into LTM. Recall performance is not always improved by extra rehearsals (e.g. Craik & Watkins, 1973; Crowder, 1982). The primacy and recency effects are thus not taken as evidence for separate short- and long-term memory any longer, and alternative accounts have been offered for the effects (for reviews see e.g. Talmi & Goshen-Gottstein, 2006; Tan & Ward, 2000). Although there are still current interpretations of the effects in terms of separate memory systems (e.g. Davelaar, Goshen-Gottstein, Ashkenazi, Haarmann, & Usher, 2005 and Davelaar, Haarmann, Goshen-Gottstein, & Usher, 2006), others have in fact taken the presence of the recency effect in both short- and long-term memory as evidence for the opposite position of one unitary memory system (e.g. Crowder, 1993). This argument will be discussed further when describing the unitary model in Section 1.3.

Different memory codes

A third argument for the proposal of separate short and long-term memory systems stemmed from the observation that there are different codes (i.e. phonological and semantic codes) for storage in memory. Conrad (1964), for instance, found that for letter strings, recall errors made by participants were typically similar in sound to the correct item, even when letters had been presented visually. Baddeley (1966a, b) studied recall of words and contrasted phonological similarity with similarity of meaning. He found that phonologically similar sets were much harder to recall than the dissimilar sets, whereas similarity of meaning had little effect. After a filled delay, however, phonological similarity has no effect anymore, and similarity of meaning affected recall instead. These results suggested that STM tends to rely on some type of speech-based code; participants remembered items in terms of their sound or phonological characteristics. LTM, in contrast, seemed to rely on semantic coding;

participants remembered items in terms of their meaning. Again, subsequent research revealed that this simple association between STM and phonological coding, and LTM and semantic coding was an over-simplification, and most researchers no longer take the different types of coding to indicate a distinction between short- and long-term stores. It is now clear that short-term storage can also contain semantic information, and long-term memory can contain information about acoustic characteristics (for a review see Neath & Surprenant, 2003; Smith & Kosslyn, 2007). For example, phonological coding is used in long-term memory in language acquisition (e.g. Baddeley, 2003a; Gathercole, 2006), and semantic coding in short-term memory is thought to be important in learning of semantic representations in long-term memory (e.g. Freedman & Martin, 2001).

Neuropsychology

Finally, evidence for the separability of short and long-term memory stores has come from neuropsychological studies of brain damaged patients, specifically of patients showing a double dissociation in impairments of short- and long-term memory. For instance, amnesic patients' explicit LTM for most types of information is impaired, and they have global impairments in the ability to acquire new memories regardless of sensory modality (Cohen & Eichenbaum, 1993; Squire & Zola, 1997). Amnesic patients, however, have been shown to have relatively spared STM for tones (Wickelgren, 1968), digits (Cave & Squire, 1992; Baddeley & Warrington, 1970; Wickelgren, 1968), words (Baddeley & Warrington, 1970; Hamann, Squire, & Schacter, 1995), single-dot locations (Cave & Squire, 1992; Olson, Page, Sledge Moore, Chatterjee, & Verfaellie, 2006a), objects (Olson et al., 2006a), and single features (Olson et al., 2006a). There is some recent evidence suggesting that STM for certain types of information (i.e. relational information or conjunctions) is affected in amnesic patients (Olson et al., 2006a, Olson, Sledge Moore, Stark, & Chatterjee, 2006b; see also Ranganath & Blumenfeld, 2005). It seems, however, that short-term retention of this type of information requires the hippocampus. Therefore, amnesic patients with medial temporal lobe damage that includes the hippocampus show impaired memory for relational information over short delays, but this STM function is relatively unaffected in other amnesic patients (e.g. Ryan & Cohen, 2004). Similar results were obtained from testing patient HM, who had part of his temporal lobes and hippocampus removed in an attempt to stop his epilepsy. HM could recall incidents from his earlier life, but his capacity for acquiring new information was drastically reduced. His STM, however, was quite normal;

HM performed above chance across delays up to 16s on a delayed matching to sample task involving ellipses (Milner, Corkin & Teuber, 1968).

On the other hand, there are patients demonstrating the converse pattern of impairments, with a deficit of short-term memory, but normal access to LTM or long-term learning. Shallice and Warrington's (1970; 1974) patient KF, for example, had a severely deficient verbal STM, as reflected by a digit span of only one item, but nevertheless exhibited normal verbal LTM as measured, for example, by paired-associate learning of words and word-list learning. Vallar and Baddeley (1984a; b; also Vallar & Shallice, 1990) studied patient PV, who presented with a similar pattern of impairments. PV had normal language production and comprehension, but suffered from a specific verbal short-term memory deficit. These patients have problems to retain even one or two digits in a sequence, but appear to have normal access to verbal LTM. Verbal long-term learning in these patients is impaired, however, when this depends critically on temporary memory for the phonological codes of verbal material, such as when learning new, unfamiliar words. Patient PV, for example, had a distinctly impaired performance on tests that required phonological analysis at the time of learning, and on tasks involving the learning of vocabulary from an unfamiliar foreign language (Baddeley, Papagno, & Vallar, 1988).

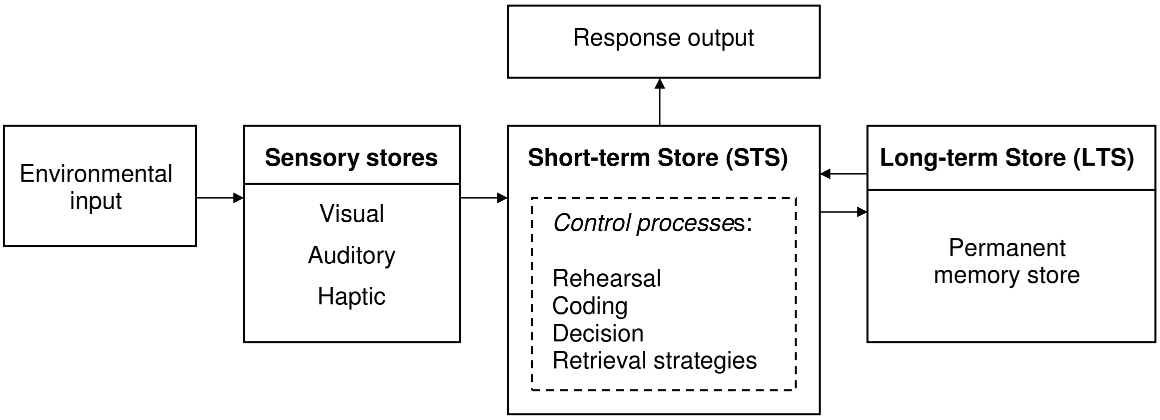
Summary

The first three observations that researchers in the second half of the twentieth century took as evidence for separate short- and long-term stores (i.e. mechanisms of forgetting, primacy and recency effects, and memory codes) have been strongly contested (and in fact, have been taken as evidence against separate STM and LTM, see Section 1.3.1). The fourth argument, however, is still very important; the double dissociation in impairments of short-term memory and long-term memory still provides crucial support for the separability of the two memory systems. More evidence for a neuropsychological double dissociation between long-term memory and short-term memory, specifically in the visual domain, is reviewed in Section 1.4.1. In the next sections, the development of the gateway view in models of memory will be discussed.

1.2.2 The gateway view in the modal model

On the basis of the early empirical data suggesting that there were separate short- and long-term memory stores, researchers began to formulate models of memory that explained the flow of information through the system. Waugh and Norman (1965), for example, proposed a model in which information from the environment first entered 'primary memory' for short-term storage. They argued that information in primary memory is displaced by new material unless it is actively maintained by rehearsal. Rehearsed material could be copied into 'secondary memory' for long-term storage. This idea was elaborated further by Atkinson and Shiffrin (1968; 1971), who proposed a model that is still referred to as the 'modal model' of memory (see Figure 1.1). In this model, STM is rather more complex, comprising certain control processes in addition to having storage function. The control processes included both verbal rehearsal and other coding strategies such as imagery. Atkinson and Shiffrin called it a system for temporarily holding and manipulating information as part of a wide range of essential cognitive tasks such as learning, reasoning, and comprehending. This idea of STM is very close to current conceptions of working memory.

Figure 1.1. Atkinson and Shiffrin's (1968; 1971) model of memory



The modal model assumes that perceptual information first enters a modality specific sensory buffer store. Sensory memory is memory in which representations of the physical features of a stimulus are stored for a very brief time (milliseconds). From these stores, information can be transferred to a limited capacity Short-Term Store (STS), which in turn communicates with a Long-Term Store (LTS). Like Waugh and Norman, Atkinson and Shiffrin saw rehearsal as the process whereby information is maintained in the STS, and postulated that the longer an item is held in the STS, the greater the probability that it will be transferred or copied into the LTS (Atkinson & Shiffrin, 1968; 1971; Raaijmakers & Shiffrin, 1980; 1992). This type of model can be referred to as a 'gateway' model, because STM (or WM) acts like a gateway for perceptual information on its way to LTM (e.g. Logie, 1995). Other terms have also been used, such as 'pipeline' model, to emphasise the unidirectional pipeline structure of the flow of information in the model (Cowan, 1988).

The modal model was able to give an account for much of the data in memory research (such as the primacy and recency effects), but there were also some problems with it (see e.g. Crowder, 1993; Groeger, 1997). One observation that could not be explained by the modal model was the presence of patients like PV (e.g. Vallar & Baddeley, 1984a; b), who presented with a selective impairment of verbal short-term memory, but with normal language production and comprehension. If short-term memory is important in complex cognitive tasks like long-term learning and comprehension (as suggested by Atkinson and Shiffrin (1968; 1971)), then patients with a deficit in this system should also have problems with these tasks. PV had no problem with language comprehension or long-term learning. Another problem with the modal model is its assumption that transfer of information from the STS to the LTS is heavily dependent on rehearsal. As mentioned above, recall performance is not always improved by extra rehearsals (e.g. Craik & Watkins, 1973; Crowder, 1982).

Despite these criticisms, however, the original modal model continues to have its proponents (see e.g. Healy & McNamara, 1996; Izawa, 1999; Raaijmakers, 1993). Many assumptions and features of the modal model are still present in more recent models that are able to explain more of the data, such as the computational Search of Associated Memory (SAM) model of memory (Raaijmakers & Shiffrin, 1980, 1992) and the Retrieving Effectively from Memory (REM) model (Shiffrin & Steyvers, 1997), a more recent modification of the SAM model. Moreover, many psychology textbooks still portray the modal model as the standard model of the memory system (e.g. Atkinson, Atkinson, Smith et al., 2003; Kosslyn & Rosenberg, 2004). The modal model also provided a foundation for the development of the concept of WM, particularly for the proposal of the multi-component model of WM by Baddeley and Hitch (1974). This latter model is one of the most influential models of WM, and is still widely applied in WM research (e.g. Baddeley, 2003b). Although in the most recent models for WM the modal model itself is not explicitly present anymore, the gateway view – the hallmark of the modal model – is still maintained in many of these newer models. The multi-component model (Baddeley & Hitch, 1974) will be described in the next section, and it will be argued that this model still incorporates the gateway view.

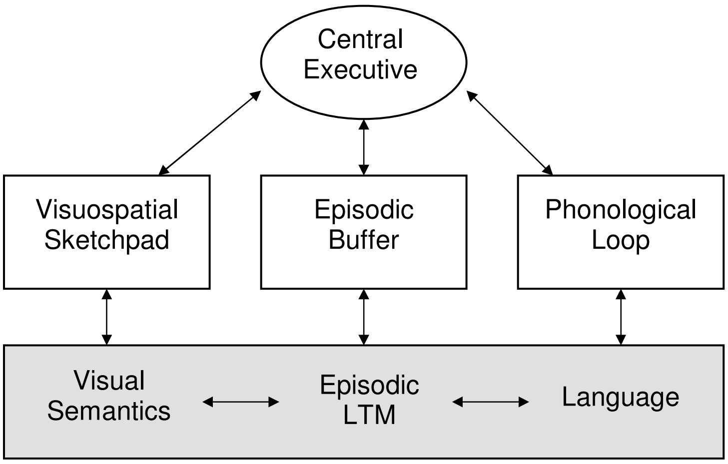
1.2.3 The gateway view in the multi-component model

Baddeley and Hitch (1974) proposed their multi-component model of working memory to extend and elaborate the functions of the STS of Atkinson and Shiffrin (1968). They argued against a unitary limited-capacity short-term store, and instead proposed the STS as a Working Memory (WM) to describe the full array of functions attributed to this system. They emphasized the combination of processing and storage as a function of WM, and stressed its role in a range of cognitive activities, such as reasoning, learning and comprehension. Most important, however, is their emphasis on the multi-component character of WM. Empirical support for this multi-component nature came from dual-task techniques, whereby participants were required to perform one task that absorbs most of the capacity of their WM (e.g. digit span), while at the same time performing each of a range of tasks such as learning, reasoning and comprehending that are assumed to be crucially dependent upon WM. In most cases, performance on the two tasks was not impaired or only slightly impaired, leading to the conclusion that certain tasks are carried out drawing only on one of a number of subsystems, leaving other components of WM relatively unaffected (Baddeley & Hitch, 1974; Hitch & Baddeley, 1976; for a review see Baddeley, 1997). There is also strong neuropsychological evidence for the existence of multiple specialised WM components. Many double dissociations are observed in the patterns of impairments and sparing following contrasting forms of brain damage (for reviews see Baddeley & Hitch, 1994; Della Sala & Logie, 1993; 2002; Gathercole, 1994). Some of this evidence will be reviewed when discussing the specific subcomponents later in this section.

The multi-component WM model consists of a controlling attentional system that supervises and coordinates two subsidiary slave systems (see Figure 1.2). The attentional controller is termed the Central Executive and the slave systems are the Phonological Loop, and the Visuo-Spatial Sketchpad. The first is assumed to be responsible for the manipulation of speech-based information and the second for generating and manipulating visual images.

More recently, a fourth component was added, namely the Episodic Buffer. These components will be described in more detail in the next sections.

Figure 1.2. The most recent version of the multi-component WM model of Baddeley and Hitch (1974) (after Baddeley, 2000, Fig 1b). The shaded areas represent crystallised (long-term memory) systems, unfilled areas represent fluid (working memory) systems.



It is important here to first emphasise a fundamental assumption of the multi-component WM model. Baddeley (2002) maintains that the phonological loop and the visuospatial sketchpad can receive information either through retrieval from long-term knowledge, or directly from perceptual input. He writes: “The sketchpad is assumed to form an interface between visual and spatial information, accessed either through the senses or from LTM” (Baddeley, 2002, p88). Elsewhere, he claims: “The two subsidiary systems (i.e. the phonological loop and the visuospatial sketchpad) themselves form active stores that are capable of combining information from sensory input, and from the central executive. Hence, a memory trace in the phonological store might stem either from a direct auditory input, or from the subvocal articulation of a visually presented item such as a letter” (Baddeley, 2000, p418, box 1). And, most recently: “(…) visuospatial information may be encoded in the sketchpad either through perception, from LTM, or via a combination of both” (Baddeley, 2007, p93). The gateway view of WM is thus still incorporated in this model; perceptual input is thought to be able to access the short-term storage components directly, even though Baddeley does not make explicit whether perceptual input could also directly activate LTM. The distinct components for verbal and visuo-spatial working memory would imply different parallel ‘gateways’ for modality-specific information. The gateway view in the multi-component model will be discussed in more detail when describing the phonological loop and visuo-spatial sketch pad.

The phonological loop

The phonological loop (originally referred to as the articulatory loop (Baddeley & Hitch, 1974)) is the best understood component of the system, and received most attention in experimental psychology. It is believed to be important in language comprehension, learning to read, and acquiring vocabulary or a foreign language (e.g. Baddeley, 2003a; Baddeley, Gathercole & Papagno, 1998). The phonological loop is assumed to comprise of two components; a phonological store, holding speech-based information, and an articulatory control process based on inner speech. Information in the phonological store is thought to decay and become irretrievable after a few seconds, unless it is refreshed (through subvocal rehearsal) by the articulatory control process. The articulatory control process is also assumed to be capable of converting visual material into a phonological code and transferring it to the phonological store. This model of verbal working memory offers a possible account of patients with a verbal short-term memory impairment but no LTM impairment, an observation which created a problem for the modal model. In terms of the multi-component WM model, these patients could be argued to have a specific deficit in the phonological loop. General performance in complex cognitive tasks could still be largely maintained by the central executive and visuospatial sketchpad (e.g. Baddeley, 2003a).

The phonological loop system is further able to account for many verbal short-term memory phenomena (see Baddeley, 2003a). For example, the phonological similarity effect – i.e. recall of phonologically similar words is worse than of phonologically dissimilar words – can be explained by the assumption of storage based on phonological coding and rehearsal. Phonologically similar items have easily confusable codes, leading to impaired recall performance (see e.g. Larsen, Baddeley & Andrade, 2000). The word length effect – i.e. better recall of short words than of longer words – can be explained in terms of the time it takes to subvocally rehearse each word in the articulatory control process (e.g. Baddeley, Chincotta, Stafford & Turk, 2002). Articulatory suppression – i.e. the repeated aloud articulation of a word or sound – interferes with short-term verbal recall, because it is assumed to block subvocal rehearsal, and the phonological encoding of visually presented material (e.g. Larsen & Baddeley, 2003). A final and important observation that can be explained in terms of the phonological loop model is the effect of irrelevant, unattended speech – i.e. reduced serial recall performance of verbal material due to concurrent irrelevant speech sounds (Salamé & Baddeley, 1982). This is assumed to occur because the speech sounds gain obligatory access to the phonological store, where the list items are disrupted by the presence of this irrelevant material, although there is still much discussion about the specific mechanism of this effect (e.g. Beaman, Bridges & Scott, 2007; Hanley & Bakopoulou, 2003; Larsen & Baddeley, 2003; Repovš & Baddeley, 2006). This is an important assumption, as it implies the gateway view: perceptual input feeds into the WM system before reaching the long-term knowledge store.

Strong support for the existence of a specialised phonological loop system, with separate storage and rehearsal components, has come from neuropsychology (see e.g. Baddeley, 2003a; Della Sala & Logie, 2002; Gathercole, 1994). For example, patients with anarthria (the complete inability to produce speech sounds) still appear able to rehearse and their immediate verbal recall (using a pointing response) is still sensitive to word length (e.g. Baddeley & Wilson, 1985). This suggests the existence of a specialised system for short-term verbal memory that is independent of the speech production system. The fractionation of the phonological loop into the phonological store and the rehearsal system is supported by demonstrations of distinctive memory profiles of patients with acquired neuropsychological deficits. An example of a patient showing such a dissociation of impairments of the store and rehearsal component is patient PV, mentioned above when discussing the dissociation between LTM and STM. PV had a highly specific impairment of verbal short-term memory; her verbal memory span was only two or three items. At the same time, her speech production, articulation rate, and written language were normal (Vallar & Baddeley (1984a, 1984b). Her span for visual material was also impaired, but was better than for verbal material. PV's recall was influenced by phonological similarity when auditory but not visual memory lists were used. Recall of visual material was uninfluenced by phonological similarity, word length, or articulatory suppression. Vallar and Baddeley (1984a) argued that PV had a specific impairment of the phonological short-term store, accompanied by a strategic choice not to use subvocal rehearsal. There is also evidence from neuropsychology that the phonological loop system for verbal short-term memory is separate from the visuospatial sketchpad for visual short-term memory. For example, patients with verbal short-term memory deficits have much higher span for visually presented verbal sequences. In contrast, healthy adults typically show higher spans for aurally presented than for visually presented verbal sequences (e.g. Logie, Della Sala, Laiacona, Chalmers & Wynn, 1996).

Also, some Alzheimer patients show a double dissociation with some patients showing a selective deficit in verbal memory span, and some in visual memory span (Baddeley, Della Sala & Spinnler, 1991). Further evidence for the separability of a verbal and visuo-spatial component in working memory comes from double dissociations in experimental psychology. Logie (1986), for example, demonstrated that a visual working memory task (the pegword mnemonic) was selectively disrupted by a visual secondary task (viewing irrelevant pictures), whereas a verbal working memory task (rote rehearsal) was selectively disrupted by a verbal secondary task (irrelevant speech).

The visuospatial sketchpad

The second subsystem in the multi-component model, the visuospatial sketchpad, is especially important in this thesis, as the experiments described in this thesis focus on visuospatial working memory. The visuospatial sketchpad is a system responsible for manipulation and temporary storage of visuospatial information. Baddeley (2003b) argued that the function of this component is important for mental synthesis, which is crucial in areas such as architecture, engineering, scientific discovery, understanding complex systems such as machinery and acquiring semantic knowledge about the appearance of objects and their function, as well as for spatial orientation and geographical knowledge (Baddeley, 2003b). Verbal material can also be stored by means of visual coding. This has been demonstrated, for example, in a series of experiments by Logie, Della Sala, Wynn, & Baddeley (2000). In this study, participants were shown sequences of four letters, with the letters appearing sequentially, in either upper or lower case. They had to recall the letters in correct order and case form. A critical manipulation in this experiment was the visual similarity between upper and lower case form of some letters. All letters were controlled for phonological similarity and for letter frequency. It appeared that participants had more difficulty in recalling case form of visually similar sets than of visually dissimilar sets, suggesting the use of a visual code to remember the verbal material. Further experiments replicated this visual similarity effect with word lists (Logie et al., 2000).

Logie (1995) argued that the visuospatial sketchpad can be broken down into two separable components for visual and spatial information. He proposed the *visual cache* as a store holding visual images that is subject to decay. The term ‘visual’ refers to the visual appearance of an object or scene, its colour, shape, contrast, size, visual texture, and the location of objects relative to one another with respect to a particular viewpoint in a static array. The spatial component, the *inner scribe,* is a system responsible for retaining spatial information, and can be used to rehearse the contents of the visual store. The term 'spatial' refers to sequential aspects of movements, or changes in the perceived relative locations of objects from a certain viewpoint to another (Logie, 1995, 2003). Evidence for the separability of a visual and a spatial component in the visuospatial sketchpad comes from neuropsychology and experimental psychology. There is a double dissociation of impairments of visual and spatial short-term memory in brain damaged individuals. Patients have been described who have a selective impairment of visual but not spatial short-term memory (e.g. Farah, Hammond, Levine, & Calvanio, 1988; Wilson, Baddeley, & Young, 1999). This type of patient generally has impaired memory for colours, objects and shapes, or has problems with visual imagery. On the other hand, they usually demonstrate intact memory for movement sequences or memory for locations, and perform normally on mental rotation tasks. There are also reports of patients with the converse pattern of impaired spatial, but intact visual short-term memory (e.g. Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001; Hanley & Davies, 1995; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998; Pisella, Berberovic, & Mattingley, 2004). This separation between visual and spatial working memory is further supported by empirical studies with healthy participants, such as the study by Della Sala, Gray, Baddeley, Allamano, and Wilson (1999). They demonstrated a double dissociation in disruption of performance on a visual pattern memory task by a visual secondary task, and of performance on the Corsi Blocks test by a spatial secondary task. The visual matrix patterns were presented simultaneously, and participants were required to recall the patterns by filling in cells on printed empty matrices. Performance on this task was significantly disrupted by viewing pictures of abstract paintings in the retention interval. The effect of the pictures on the Corsi Block task – which involves reproducing a sequence of movements by tapping blocks on a board, and is regarded as a spatial working memory task – was much smaller. In contrast, a secondary spatial tapping task (i.e. tapping four blocks clockwise) interfered significantly more with the Corsi Block task than with the visual patterns task. These results thus provide further support for the distinction between the visual cache and the inner scribe within the visuospatial sketchpad of working memory. Besides a distinction between visual and spatial storage and processing in WM, some researchers have argued that a distinction should be made also between active and passive processing (e.g. Mohr & Linden, 2005; Vecchi & Cornoldi, 1999). Passive processes are argued to be required in the recall of information in the same format as it was memorised, while active processes are recruited by tasks that require the information to be modified, transformed, integrated or otherwise manipulated. There is indeed some recent evidence that serial sequential visuo-spatial tasks involve executive resources to a greater extent than do simultaneous visuo-spatial tasks (e.g. Rudkin, Pearson & Logie, 2007). However, visual and spatial short-term retention can be dissociated when style of presentation (i.e. simultaneous or sequential) is controlled for (e.g. Darling, Della Sala, Logie & Cantagallo, 2006).

Studies investigating the selective interference effects of secondary tasks on visuo-spatial short-term memory tasks, like the experiment by Della Sala et al. (1999) described above, have contributed importantly to our knowledge about the functioning of the visuospatial sketchpad. A widely used technique to interfere selectively with visual working memory is irrelevant visual input, somewhat analogously to the use of irrelevant speech to interfere with verbal working memory. Some researchers have argued that irrelevant visual input has direct access to the visual cache, much like irrelevant speech is assumed to have direct access to the phonological store (e.g. Andrade, Kemps, Werniers, May, & Szmalec, 2002; McConnell & Quinn, 2004, Quinn & McConnell, 2006). Quinn and McConnell, for example, have proposed a model for visual working memory based on Baddeley's conception of the visuo-spatial sketchpad, and Logie's distinction between a visual cache and an inner scribe, but have proposed an additional component that they hold responsible for conscious visual imagery, namely the 'passive visual store'. They compare this component to the 'visual buffer' in Kosslyn's influential model of visual imagery (e.g. Kosslyn, 1980, 2005). They suggest that the visual cache rather is a store that holds interpreted information from LTM, and that is not directly accessible form external sources. The passive visual store, they argue, is also a visual short-term memory store, but this structure is used for conscious visual imagery (Quinn and McConnell, 2006). They claim that this store can be front-loaded by perceptual input (McConnell & Quinn, 1996; 2000; 2003; 2004; Quinn, 1996; Quinn & McConnell, 1996a; 1996b; 1999; 2006). Similarly, Pearson (2001; Pearson, De Beni, & Cornoldi, 2001; Pearson, Logie, & Gilhooly, 1999) argued for an addition to Logie's (1995) view of visuo-spatial working memory. He argues that an extra visual buffer is needed to subserve conscious visual imagery, and that the visual cache rather acts as a temporary back-up store for non-conscious visual representations. Pearson describes his visual buffer as a structure that holds conscious mental images, "generated either from representations stored in long-term visual memory, or loaded directly from the perceptual systems in the form of visual traces" (Pearson, 2001, pp 51). Again, this points to the gateway view, in which perceptual information can have direct access to the WM system. There is an important difference, however, between Pearson's (and also Logie's) conception of a buffer and the conception of Quinn and McConnell. The buffer of Logie and Pearson is not regarded as a visual memory substrate, but more as an executive process. This issue will be discussed further in Section 1.5.2 in this chapter. The literature on interference effects of irrelevant visual input on visual WM will be discussed in detail in Section 1.5.1.

The central executive

The central executive is the system thought to be responsible for control and coordination of the two slave systems. Baddeley (2003b) concluded that the central executive is the most important but least understood component. It is assumed to be important for the capacity to focus, divide and switch attention, as well as in complex cognitive tasks such as reading, language comprehension, reasoning and decision-making (e.g. Baddeley, 1996, 2002, 2003b). Baddeley and Hitch's (1974) original model assumed that the central executive could be used for supplementary storage in addition to support control processes. This idea has been revised since, however, partly based on dual-task experiments that demonstrated that there was no interference between storage and processing tasks, suggesting that these do not compete for a single resource (e.g. Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002; Duff & Logie, 1999). Much of the experimental work to explore the central executive has focused on patients with Alzheimer's disease. These patients seem to have a specific impairment in functions attributed to the central executive. Alzheimer patients have been demonstrated, for example to show clear deficits related to the requirement for dual tasking (e.g. Baddeley & Della Sala, 1996; Logie, Cocchini, Della Sala, & Baddeley, 2004). A technique also widely used in research on the role of the central executive in cognitive processes is random generation (e.g. Baddeley, 1996; 1998). It is argued that this task selectively loads the central executive component within working memory, and interferes with the ability to switch attention from one source to another (e.g. Baddeley, 1998). Vandierendonck, De Vooght, and Van der Goten (1998), for example, demonstrated that a random generation task disrupted supra-span serial recall and backward memory span. These effects were observed in dissociation with effects of articulatory suppression and matrix tapping, suggesting that the effect of random interval repetition was not due to disruption of the phonological loop or visuo-spatial sketch pad (Vandierendonck et al., 1998).

The episodic buffer

The most recent, fourth component of the working memory model is the episodic buffer. The development of the episodic buffer stemmed from a number of observations that could not be explained by the model with the existing three subcomponents (Baddeley, 2000). One such problem is presented by studies on the recall of prose. Whereas word recall span is usually around 6 to 7, in case of prose (i.e. meaningful sentences) span can increase to 16 or more, reflecting the ability of ‘chunking’. Chunking depends on integrating the constituent words into small groups (‘chunks’) on the basis of additional information from LTM. The original three-component model has difficulty in explaining how material from different sources is integrated, and where the chunks are then stored (Baddeley, 2000). Other problems of the three-component model are the lack of a mechanism for allowing the phonological and visuo-spatial subsystems to interact, and a mechanism for the role of WM in conscious awareness (e.g. Baddeley & Andrade, 2000). The episodic buffer was proposed to account for these and other issues. It is assumed to be a limited capacity system that depends heavily on executive processing, but that differs from the central executive in being principally concerned with the storage of information rather than with attentional control. It is held capable of binding together information from a number of different sources into chunks or 'episodes', and is a buffer in the sense of providing a way of combining information from different modalities into a single multi-faceted code (Baddeley, 2003b). The suggestion of an episodic buffer being responsible for the benefit in recall of prose is supported by a range of subsequent studies – for example a case study of an amnesic patient by Baddeley and Wilson (2002). This patient was densely amnesic, but showed normal immediate memory for passages of prose comprising many different ideas and extending well beyond the capacity of the phonological loop or the visuospatial sketchpad (Baddeley and Wilson, 2002).

Allen, Baddeley and Hitch (2006) recently investigated the role of the episodic buffer in binding in visual working memory. Binding refers to grouping together different features of an object such as colour and shape, and maintaining them separately from features belonging to other objects in memory (Allen et al., 2006). Allen et al. emphasise that in the multi-component WM model with the episodic buffer, it is assumed that access from the phonological loop and visuospatial sketchpad to the episodic buffer occurs through the central executive. They argue that therefore any form of binding that requires encoding and/or maintenance in the buffer will be particularly dependent on general attentional resources provided by the executive. In their series of experiments, they did not find any evidence that encoding feature configurations into visual WM was demanding of executive resources. They interpret these results in terms of the existence of two types of binding processes; (1) passive automatic binding in visual WM, and (2) more controlled active attention-demanding binding, with the assumption that executive processes will be involved in the active, but not automatic binding (Allen et al., 2006).

Summary

The multi-component model has proven very fruitful and durable in research in many areas of cognitive psychology. It was able to address issues that the modal model could not account for, such as the existence of patients with impairments in verbal short-term memory, but intact LTM learning and perception. As Baddeley claims, "for many years it formed a productive basis for the systematic accumulation of knowledge about important cognitive capacities" (Baddeley, 2002, p.94). However, in this thesis it will be argued that one problem with the model is its incorporation of the gateway view of WM. As pointed out in this section, it is commonly assumed that verbal as well as visual perceptual input can have direct access to the WM components. The problem with this view will be outlined in Section 1.4.1.

1.3 THE UNITARY MODEL

In the unitary model, working memory is seen as comprising the activated subset of long-term memory representations. The origin of this model lies in the rejection of the view of separate stores for short- and long-term memory. Arguments that led to this rejection will be reviewed in this section, as well as an influential current model of working memory based on the unitary memory view, i.e. the "embedded processes model" of Cowan (e.g. 1988, 2005). When this thesis refers to the unitary view of the interaction of WM and LTM, it is specifically with Cowan's model in mind, as his model is the most elaborated and well-known example of the unitary view.

1.3.1 Behavioural evidence for the unitary model

Although in the 1960's evidence accumulated that suggested that there were separate short and long-term stores, this conclusion has always remained a major controversy in psychology research. Several researchers opposed the view of separate short- and long-term memory stores, and advocated a unitary view of memory (e.g. Melton, 1963; Norman, 1968; Postman, 1975). The unitary view has also been called the 'monistic view' (e.g. Cowan, 1995), or 'proceduralist view' (e.g. Crowder, 1993). These researchers questioned whether it is necessary or useful to assume that short- and long-term memory are separate cognitive systems. Instead, they claimed that both STM and LTM reflect the operation of a single unitary system and conceptualise memory as a continuous process rather than as a set of distinct task-specific stores. The debate over separate stores for short- and long-term memory is still ongoing (e.g. Cowan, 1995; Neath, Brown, Poirer & Fortin, 2005; Ranganath & Blumenfeld, 2005). Protagonists of a *unitary model* often claim that it has the advantage of parsimony over models that postulate distinct short and long-term memory stores (e.g. Postle, 2007; Ruchkin, Grafman, Cameron, & Berndt, 2003). Arguments for the unitary model of memory have come from neuro-imaging as well as behavioural studies.

One argument that has been used to support a unitary memory view is the observation that STM and LTM are associated with similar memory phenomena. This observation has led researchers to conclude that it is redundant to postulate two different stores (e.g. Crowder, 1982; 1993; Nairne, 2002). Crowder (1993) argued that the procedures that previously had been taken to index short-term storage could be accounted for entirely according to the properties of a single memory store. For example, in Section 1.2.1 it was discussed that forgetting in STM and LTM could both be explained in terms of interference, rather than having to assume trace decay as a specific mechanism for STM. Forgetting in the Brown-Peterson paradigm, which has traditionally been seen as a benchmark finding on the capacity of short-term memory, was better explained by factors associated with long-term memory, such as proactive interference and retrieval cues (e.g. Lewandowsky et al., 2004; Melton, 1963; Nairne, 2002; Neath, 2006). A second similarity is that long-term learning has also been demonstrated in short-term memory tasks, for instance in the Hebb effect (Hebb, 1961). The Hebb effect was originally demonstrated in a task involving the immediate recall of sequences of random numbers. The sequences are always the same in length, just beyond the span of the participant. One sequence in the list is repeated every three presentations, without the participant being aware of it. Under these circumstances, the probability of recalling the repeated sequence correctly increases over successive presentations, which is seen as evidence for long-term learning (Hebb, 1961; see also Burgess & Hitch, 2005; Hitch, Fastame, & Flude, 2005). Thirdly, as discussed in Section 1.2.1, the recency effect appeared to not be restricted to immediate recall tasks, but also occurs for longer term memories, both in real-life situations as well as in experimental laboratory settings. These long-term recency effects have been taken as evidence for a unitary view of memory (e.g. Crowder, 1993, but see e.g. Davelaar et al., 2006 for an alternative interpretation in terms of separate short- and long-term stores). Another similarity between STM and LTM, taken as evidence for the unitary model concerns the memory codes used for storage. An apparent association between STM and phonological coding, and LTM and semantic coding, was originally taken as evidence for separate memory stores. However, it is now clear that both phonological and semantic coding are used in short- and long-term memory (see Section 1.2.1). These observations led proponents of the unitary view to conclude that STM and LTM follow similar rules and reflect the operation of one unitary system (e.g. Crowder, 1993; Nairne, 2002). However, the interpretation of these observations is still much discussed (see also Section 11.3 in this thesis).

1.3.2 Evidence from neuro-imaging studies

A common conceptualisation of the unitary view of memory is the suggestion that short-term memory could be seen as activated long-term memory (e.g. Cowan, 1988, 1999, 2005). This suggestion is not new. Hebb (1949) already proposed a ‘dual-trace mechanism’, suggesting that STM and LTM can be supported by the reactivation of neural networks. Also Atkinson and Shiffrin (1971), after the proposal of their modal model (1968), emphasised that their model did not require that the short and long-term store were implemented in different areas of the brain, or that they involved different physiological structures. In fact, they proposed that the short-term store might simply be a temporary activation of some portion of the long-term store. Recently there has been a wealth of studies dedicated to investigate this view, using neuro-imaging techniques. These studies have provided some evidence that the same brain regions underlie perception, working memory retention and retrieval from long-term episodic memory. A recurrent finding from these studies is that short-term retention processes involve both frontal and posterior cortical regions, and these same regions are also involved in perception and comprehension of visuo-spatial and verbal information. The following section is not intended to be an exhaustive review of all of these studies (for reviews, e.g. Postle, 2007; Ruchkin et al., 2003), but will discuss some relevant examples to illustrate the type of evidence brought forward for the unitary model.

Courtney, Ungerleider, Keil, and Haxby (1997) used fMRI to measure changes in neural activity over the course of a WM task in order to distinguish the perceptual and mnemonic roles played by the cortical regions that participate in visual WM. Participants were presented with a sample picture of a face for 3s, then had to keep this image in mind for 8s, and had to make a same/different judgment upon presentation of a test face. In a control task they saw pictures of scrambled faces and had to make random responses without trying to remember the images. The fMRI analyses revealed transient, non-selective activity in ventral occipito-temporal extrastriate visual areas that was correlated with stimulus presentation. A later transient, more selective, response occurred in a ventral temporal region in the mid-to-anterior fusiform gyrus. This area also showed sustained activity during the memory delay. Furthermore, a number of distinct prefrontal areas were identified that all showed sustained activity during the memory delay interval (Courtney et al., 1997). Ruchkin, Johnson, Grafman, Canoune and Ritter (1997b) have studied the process of WM retention with ERP, yielding better temporal resolutions. They found that in a visual memory task, there is early ERP activity in the primary visual cortex, mainly during stimulus presentation and little in the subsequent retention interval. There was long duration transient activity in the posterior temporal lobes after stimulus presentation and sustained activation in both prefrontal cortex and posterior visual processing pathways during retention. In an object memory task the sustained activity was in the anterior temporal lobes (ventral pathway), and in a spatial memory task it was near the junction of parietal and occipital cortex (dorsal pathway). In the object task, where all the information to be retained was available at stimulus onset, sustained activity in the anterior temporal lobe started during stimulus presentation. The spatial task required memorization of a sequence of movements, with the last movement beginning 1500 ms after the stimulus began. In this case, sustained activity near the junction of parietal and occipital cortex did not begin until presentation of the stimulus sequence was complete. In both tasks, the onset of the sustained activity observed in the dorsal and ventral visual processing pathways was 60 to 300 ms before the onset of the sustained activity observed in prefrontal cortex (Ruchkin et al., 1997b).

The observation that visuo-spatial retention involves areas also implicated in perception of the same stimuli, has also been made for verbal material. Hickok and Poeppel (2000), for example, found that passive listening to speech stimuli – which they argued must activate

LTM and/or perceptual processing systems for verbal material – resulted in activation of superior temporal regions bilaterally. In two further fMRI studies they demonstrated that these same areas were also activated in a task in which participants were presented with acoustic speech information, which they had to rehearse subvocally during a retention interval (Buchsbaum, Hickok, & Humphries, 2001; Hickok, Buchsbaum, Humphries, & Muftuler, 2003). They found activity in two frontal regions (Broca's area and a premotor site), thought to be involved in articulatory rehearsal. Additionally, they found activation in the superior temporal sulcus bilaterally, and in the left Sylvian fissure at the parietal-temporal boundary. The superior temporal sulcus regions activated in this study, clearly mapped onto regions that were implicated in auditory speech perception/comprehension (Hickok & Poeppel, 2000). Hickok and Buchsbaum (2003) argue that these studies provide strong support for the hypothesis that verbal WM is an active state of more fundamental processing/representation systems.

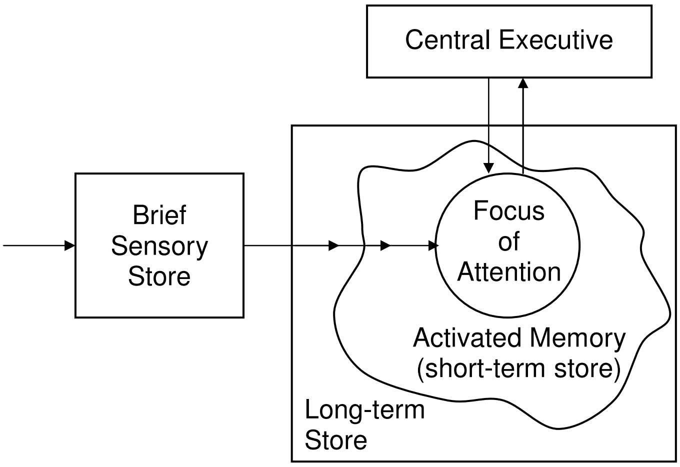
Many other studies have supported this observation of an overlap of areas involved in perception, retention in WM and activation from LTM (e.g. Awh et al., 1999; Awh & Jonides, 2001; Haxby, Petit, Ungerleider, & Courtney, 2000; Jonides, Lacey, & Nee, 2005; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Slotnick, 2005; Wheeler et al., 2000, for reviews see Postle, 2007; Ruchkin et al., 2003, and specifically for the area of visual imagery: e.g. Denis & Kosslyn, 1999; Ganis et al., 2004). The overall pattern that seems to emerge from these findings is that retention of information in WM involves sustained activation of posterior and frontal brain systems. The posterior areas are also the location of LTM systems that are initially activated for the processing of perceptual information. Postle (2007) argues that, in this context, the term LTM has to be taken in the broadest sense: as areas involved in perceiving, recognizing, understanding, and rehearsing as abilities that we have acquired as a result of experience. The observation that brain activity during retention is influenced by the type of information (i.e. visual, spatial and verbal) held in short-term memory, is interpreted as evidence that information in WM comprises activated parts of specialised areas in LTM (e.g. Crowder, 1993; Ruchkin et al., 2003). Ruchkin et al. (2003) proposed that once LTM areas have been activated by perception, subsequent interactions with other cortical systems in the prefrontal area are hypothesised to sustain activation of the LTM networks, thereby enforcing temporary retention of the information. Attentional systems (located in the frontal cortex) presumably have an important role in this maintenance process. This is supported by findings of attention-based maintenance for visuo-spatial material (e.g. Awh et al., 2000; Awh and Jonides, 2001). Ruchkin et al. (2003) argue that in this view, there is no reason to posit specialised neural systems whose functions are limited to those of short-term storage and are distinct from long-term memory systems (a different interpretation of these data that rather supports separate systems, will be discussed in Section 1.4.2).

1.3.3 Cowan's Embedded-Processes Model

The idea of short-term memory as activated long-term memory is a key aspect of several currently popular models of working memory (for reviews see Logie & D'Esposito, 2007; Miyake & Shah, 1999; Osaka, Logie & D'Esposito, 2007). One of these is the 'controlled attention' framework of Engle and colleagues (e.g. Barrett, Tugade & Engle, 2004; Engle, 2002; Engle, Kane & Tuholski, 1999). This model focuses on explaining individual differences in working memory capacity in terms of executive control. Executive control is assumed to be required in the activation of long-term memory representations to bring and maintain these into focus, particularly in the face of interference or distraction. Another model of working memory based on long-term memory activation is the model of Ericsson and Kintsch (1995; see also Ericsson & Delaney, 1999). They proposed a system called *Long-Term Working Memory*, which is seen as a mechanism for storage in LTM used in skilled or expert working memory performance. Their model is thus not entirely unitary, but instead they propose a very intimate link between working memory and long-term memory. Baddeley has compared the concept of long-term working memory to the episodic buffer (e.g. Baddeley, 2002).

One of the most influential conceptualisations of the unitary view is the model proposed by Cowan (1988; 1995; 1999; 2001; 2005; Cowan, Morey, Chen, & Bunting, 2007). This model will be a focus in this thesis, and will be used as a framework of the class of unitary models to interpret the results of the experiments described in this thesis. Cowan (1988) proposed a new model of the human information processing system, including memory storage and selective attention. He developed his view on the basis of some problems with the gateway model of information processing (which will also be discussed in section 1.4.1). He reviews arguments against the multi-store character of the original model, and against the order of the stores through which information is processed. As a solution, he proposed a model in which short-term storage consists of the elements within the long-term store that are currently in a heightened state of activation: an idea that was not new (see e.g. Norman, 1968), but that he elaborated further. In Cowan's model (see Figure 1.4), perceptual information first enters sensory storage, which preserves most of the physical properties of stimuli. Cowan (1988) defines two stages of sensory storage (in both the visual and auditory domains): an initial phase lasting several hundred milliseconds, in which there is an unanalysed trace of the stimulus capable of extending its apparent duration (i.e. this memory is experienced as sensation), and a second phase lasting some seconds, in which there is partly analysed information (this memory is experienced as a vivid recollection of the stimulus). During the first phase, information in long-term memory becomes activated and coding operations occur. An activated subset or (non-sensory) short-term storage then emerges. There is evidence that the second phase of sensory storage can last up to 10-20 seconds. However, Cowan argues that this phase is simply a characteristic of the short-term store (activated long-term memory), given that this phase appears to be the retention of a stimulus that already has been partly processed automatically. Also, estimates of the duration of short-term memory that have been obtained seem similar to the estimates of the second phase of sensory memory, both types of storage are capacity limited, information in both types of storage can be outside of awareness, and coding in both types of storage is similar (Cowan, 1988).

Figure 1.4. Cowan's Embedded-Processes Model of working memory (adapted from Cowan, 1988, Fig 1)



Cowan defines working memory as the cognitive processes that retain information in an accessible state, as required in any task in which information has to be kept in mind. In his model there are three main (embedded) components, which are all seen as contributing to working memory: (1) long-term memory, (2) activated long-term memory – or short-term storage, and (3) the focus of attention. The focus of attention is a subset of the activated subset of long-term memory, and is associated with conscious awareness. It is controlled by a combination of automatic orienting responses to changes in the environment and voluntary effort arising from central executive processes. Many sensory features, for example, can be activated automatically, whereas semantic features are more likely to be activated with the help of attention to the stimuli (Conway, Cowan, & Bunting, 2001). Sensory input is argued to come from either familiar (unchanged) or unfamiliar (novel) stimuli. Unfamiliar stimuli are automatically attended to. Familiar stimuli can be voluntary attended to or can be habituated. Attended stimuli reach the focus of attention; the non-attended stimuli do not reach the focus but become part of the activated long-term memory (short-term store) (Cowan, 1988; Cowan et al., 2007). Cowan argues that whether or not one becomes aware of a certain stimulus depends on whether the level of activation of long-term memory exceeds the 'awareness level' (Cowan, 1995). When attention is focused on one source of information, the greatest level of activation of LTM is achieved. This level of activation exceeds the awareness level and the information is consciously perceived and is capable of guiding intentional actions. When the activation of LTM is produced by sources of information other than the attended source, this activation is attenuated, but still capable of activating relevant memory representations, sufficiently to support perception. Depending on the level of this activation, these unattended sources of information may be either unconsciously or consciously perceived. Unconsciously perceived information is also capable of influencing actions, but not necessarily in a manner that is consistent with current conscious intentions (Cowan, 1995). Cowan (1999) thus sees the information in the focus of attention as the most readily accessible information in working memory. Information that is activated, but not to the point of conscious awareness, can also be retrieved reliably, but the process is slower. An item that is not in an activated state can still be thought of as in working memory, if there are cues in working memory that point to the item and raise the likelihood that it could be retrieved if necessary (Cowan, 1999).

A central executive (i.e. effortful, limited capacity control processes) is thought to direct the process of voluntary attention, during which items are intentionally placed in the focus of attention. It is also kept responsible for the voluntary retrieval and activation of information from long-term storage. Attention can thus be directed outward, to stimuli, or inward, to long-term memories (Cowan, 1988; Cowan et al., 2007). Another function attributed to the central executive is short-term retention and processing, through the continued activation of

LTM items in the focus of attention (which could be seen as some kind of rehearsal process). In Cowan's view, short-term retention could be regarded as an 'inhibitory process', which maintains attention only on the activated part of LTM that is currently in the focus of attention, but prevents other activated memory traces from entering the focus. This inhibitory process is a cognitively effortful process. Cowan argues that the difficulty of keeping items in working memory is thus in inhibiting (or deactivating) the items that are not relevant to the task at hand, thereby allowing WM to focus on the task-relevant items (Cowan et al., 2007). An important consequence of the fact that the central executive functions are effortful, demanding processes, is that the focus of attention is capacity limited, i.e. there is a limitation in how much information (i.e. chunks) can be included in the focus of attention at one time (Cowan, 1988, 1995). The limited attentional resource must be shared between external stimuli and long-term memories activated through voluntary thought (Cowan, 1988). Short-term storage is furthermore thought to be capacity limited as a result of decay of activation and of a limitation in how much of long-term memory can be activated at once.

Cowan (1988; 2001) assumes that short-term storage of different types of information (phonological, visual, semantic, etc) is implemented in the activation of distinct areas in LTM (see also Ruchkin et al., 2003). In this view, all short-term storage has a common mechanism and properties (Cowan, 2001). This is opposed to the view of separate, distinct modules for modality-specific short-term storage, such as the phonological store and the visual cache (e.g. Baddeley, 2003b). Also, in Cowan's model, the rehearsal systems of the multi-component WM model, the phonological loop and the inner scribe, are both functions of the central executive. Object manipulation such as mental rotation would be accomplished when the central executive repeatedly reads the current contents of the activated visual store and computes (and activates) an image that differs from the current image by a small transformation (Cowan, 1988). Cowan's model is thus consistent with the unitary view of memory in that it denies the existence of separate STM structures. However, Cowan still retains the idea of separate short- and long-term memory *processes* (Cowan, 1999; 2003, Cowan et al., 2007). He acknowledges that there are differences in timing, control and capacity between short-term and long-term memory storage. However, he claims that the distinct properties of short-term storage may be consequences of the types of processing that keep memories in an active state (e.g. rehearsal), whereas the distinct properties of long-term storage may result from types of processing that are useful for efficient retrieval (e.g. semantic elaboration) (Cowan, 1988).

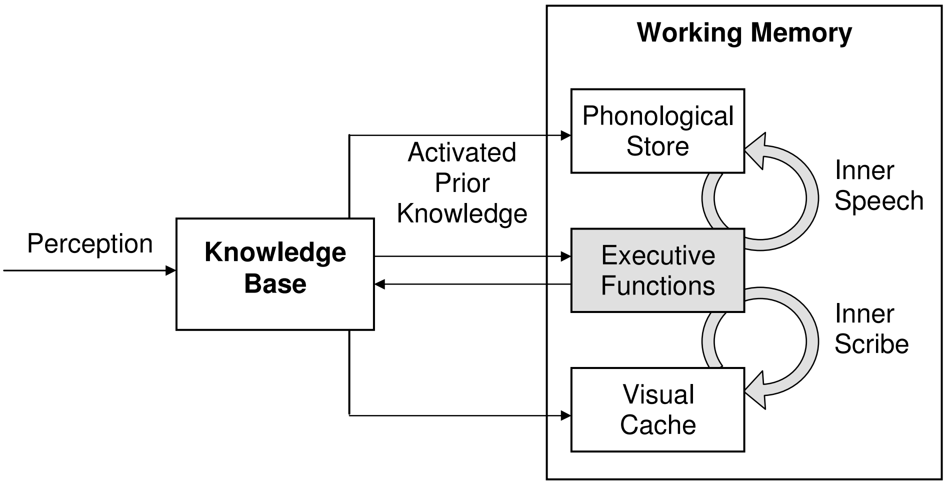
Summary

In Cowan's view, working memory consists of long-term memory, activated long-term memory, and activated long-term memory that is in the focus of attention. Deployment of attention is a crucial feature of Cowan's and other unitary models, with attention sustaining and limiting activation of long-term memory (and hence short-term storage). A number of problems associated with seeing working memory as activated long-term memory are discussed in Section 1.4.2 of this chapter. One observation that is inconsistent with the unitary view is that short-term memory and long-term memory can be impaired independently of each other. The resistance to dual-task interference creates another problem for the unitary model.

1.4 THE WORKSPACE MODEL

A third model of the interaction between working memory and long-term memory is the workspace model (Logie, 1995, 2003), which was developed as a reaction to a number of crucial problems with the gateway and unitary models (discussed in the next two sections). This model combines the explanatory power of the multi-component model of working memory (Baddeley, 2003b; Baddeley & Hitch, 1974) and the notion that the contents of working memory comprise activated information from long-term memory (e.g. Cowan, 1988; 2005), but it differs fundamentally from the gateway and unitary views of memory (Baddeley & Logie, 1999). Unlike the unitary model, the workspace model assumes functionally separate stores for short- and long-term memory. Furthermore, in the workspace model all perceptual information is assumed to first access previously stored knowledge, before further processing in working memory occurs (see Figure 1.5).

Figure 1.5. The working memory model as proposed by Logie (1995; 2003) (adapted from Logie, 2003, Fig 2)



Working memory is thus thought of as a functionally separate mental workspace that holds and manipulates verbal and visuo-spatial information activated from LTM. Long-term memory can be activated through sensory perception, but also through directed retrieval to WM, without perception (Logie, 1995; 2003). The idea of perceptual input first activating long-term memory (rather than being directly represented in working memory) had already been proposed earlier (e.g. Atkinson and Shiffrin, 1971; Bower & Hilgard, 1981; Broadbent, 1984; Shiffrin, 1975, 1976), but was further elaborated by Logie (1995). This alternative model of the interaction between WM and LTM is able to account for a number of phenomena that the gateway and unitary models have difficulty with. These problems with the gateway and unitary model will be discussed in the following two sections.

1.4.1 Problems with the gateway model

There are a few fundamental problems associated with the view of WM as a gateway for perceptual information on its way to LTM. One problem is that this view implies that perceptual material entering the WM system would not be interpreted. Another problem with the gateway model is that it has difficulty explaining how neuropsychological impairments of working memory can be accompanied in the same patient with no deficits in accessing or retrieving from LTM. Finally, the gateway model cannot easily account for the phenomenon of semantic processing of implicitly perceived information.

The contents of working memory are interpreted

An important consequence of viewing working memory as a gateway for perceptual information on its way to the long-term knowledge base is that the contents of working memory would not be interpreted in any way. Successful identification of perceptual information as recognisable objects or scenes requires access to the store of knowledge that has accumulated from prior experience (e.g. Bower & Hilgard, 1981; Della Sala & Logie, 2002). Therefore, if visual perceptual input had direct access to the WM system *before* activating LTM, the contents of the visuo-spatial WM store would consist of raw sensory images of edges, contours, shades and colours, derived directly from the environment. However, this is not the case; the visual images we hold in WM are objects or scenes that have been identified and that draw on our knowledge base. The representations in WM have associated meaning drawn from our previous experience with the object. This suggests that the temporary representations in WM are the result of activating information from LTM. In this view, perceptual input must first have activated previously stored knowledge *before* having access to WM, and WM could not be a gateway to LTM (Logie, 2003; see also Neath et al., 2005).

Some evidence that supports this view has come from the area in experimental psychology of mental discovery and creativity. Working memory can be used to mentally generate new ideas or images of new physical objects, by recombining or reinterpreting aspects of existing knowledge. Logie (2003) argues that a possible reason why creative thinking is difficult for many people is because this reinterpretation of knowledge is inhibited by the current interpretation of the contents of WM. Support for this hypothesis comes from a series of experiments by Chambers and Reisberg (1985, 1992), who demonstrated that participants had difficulty in reinterpreting ambiguous figures from mental images. Participants were shown the Jastrow duck/rabbit figure for 5 seconds. This period was long enough for participants to memorise the figure, but too short for participants to reconstrue (detect the alternate interpretation) the picture itself while it is still in view. This was important because the aim of the experiment was to investigate whether participants were able to discover the alternate construal from their images. It was therefore also crucial that participants did not know about the alternate construal prior to creating the image. After 5s, the duck/rabbit picture was removed from view, and participants were asked to form an image of this shape. Participants were given unlimited time to form this image, and were then asked to try to reconstrue the image. Participants were given a series of hints which normally help people to reconstrue the figure if the actual duck/rabbit picture is in view. If subjects failed in this task, they were given a blank piece of paper and were asked to draw a picture of the form they had been imaging, and to try reconstruing their own drawings. The results were very clear: all of the participants failed to reconstrue their own mental image, but all were able to reconstrue their own drawings, that were based on the mental image. Moreover, these results were replicated when participants were specifically instructed to make their image a clear and precise copy of the original form (i.e. when they were warned against biasing their image to make it more 'duck-like' or more 'rabbit-like'). Logie (2003) concludes that not only was there an interpretation linked to participants' representations in WM, but removing or altering that interpretation was extremely difficult when based on the representation in WM alone.

When attempting to interpret a perceptually ambiguous figure, people use a reference frame comprising contributions from perception (e.g. the spatial orientation of the figure, its configuration in depth, its figure/ground organisation), leading them to understand the figure in a particular way (Barquero & Logie, 1999). For example, if the ambiguous duck/rabbit figure is first understood as representing a duck, the perceptual reference frame determining that interpretation seems to anchor the inspection and manipulation of the mental image of that figure and consequently to make difficult the discovery of the alternative interpretation as a rabbit. However, it was found that providing participants with explicit hints about the orientation and category of the second interpretation showed a beneficial effect on reversals (Brandimonte & Gerbino, 1993; Peterson et al., 1992). These explicit hints are thought to act on people's understanding (i.e. semantic interpretation) of their images. Furthermore, Brandimonte and Gerbino (1993) found that if measures are taken to try and prevent an interpretation being formed upon first presentation of a stimulus (through the requirement of articulatory suppression), participants are better at reporting alternative interpretations of ambiguous figures. Their general procedure was similar to that of Chambers and Reisberg (1985). During the initial memorisation of the target form, half of the participants remained silent. These participants were assumed to be able to (covertly) verbally code the picture and therefore interpret the picture semantically. Another group of participants, while memorising the target form, were required to engage in articulatory suppression. It was argued that this verbal task occupies articulatory control processes and therefore prevents verbal encoding of the picture, and forces them to use a more purely visual code. These participants were thus thought to have available a clearer, more accessible image of the picture. Indeed, Brandimonte and Gerbino found that a much larger percentage of participants in the verbal suppression group than in the control group were able to reverse the image. Moreover, articulatory suppression while inspecting the image, rather than during the initial encoding of the target form had no effect.

Reisberg, Smith, Baxter, and Sonenshine (1989) obtained similar results with auditory images. In these studies, they exploited the fact that certain words if repeated aloud yield sound-streams compatible with more than one segmentation. For example, repetitions of the word LIFE yield a sound-stream that is acoustically indistinguishable from that resulting from repetitions of the word FLY. The difference between these two sound-streams lies entirely in how the sound-streams are perceptually segmented. These sound-streams are thus ambiguous in a way similar to that in which the duck/rabbit figure is ambiguous. Reisberg et al. (1989) used the stimulus word STRESS, and found that all participants reported that they perceived the sound-stream as flip-flopping between interpretations; first as STRESS, then as DRESS. This was true whether participants produced these repetitions aloud themselves, or when they heard them. A different group of participants was simply asked to guess what the word STRESS would turn into if repeated aloud, but they were not explicitly instructed to imagine hearing the sound. They produced a number of responses, mostly based on letter rearrangements (e.g. 'ester' or 'rests'). However, they rarely produced the DRESS response. Even further reduced numbers of reversals of the auditory images were achieved by preventing participants from subvocalising the presented word (by instructing them to push their tongues up against the roof of the mouth, to clench their teeth, and also to purse their lips). Again, these results suggest that our mental representations carry meaning, and that it is very difficult to dissociate the interpretation from the representation.

More support for the claim that the contents of WM are interpreted comes from studies of mental synthesis tasks. In these tasks, participants are asked to generate a mental image of a small number of shapes, and to combine the shapes mentally such that they form a recognisable object. For example, in a study by Barquero and Logie (1999), participants appeared able to do this task if the shapes they had to work with were familiar, canonical shapes, such as a circle, a triangle and a square. However, when participants were given names of real objects to work with, such as a trash can, a rugby ball and a tennis racket, many of them had difficulty performing this task. In a second experiment it was demonstrated that the difficulty in this task could not be attributed to complexity or number of objects participants were asked to work with. Rather, it was the semantic interpretation of the items that was crucial for inhibiting mental synthesis. Participants had difficulty dissociating the object identity from its shape to allow mental manipulation and combination of the shapes to form different objects (Logie, 2003).

Taken together, the results suggest that WM deals with interpreted, identified representations, not just with shapes. This presents a fundamental problem for the gateway view of the interaction between working memory and long-term memory. Models that adopt a gateway view would have difficulty explaining the results set out above. If all perceptual input has direct access to the representational system, an image that is directly loaded from perceptual input would not be interpreted. Only consequent interactions with long-term memory allow for the successful identification or interpretation of the images. To explain the difficulty that participants may have in reinterpreting visual mental images, one would have to assume that visual perceptual input first accesses visual working memory, is then further processed to activate long-term memory structures, and would subsequently be transferred back into the working memory system for further mental manipulation after it has been identified. It is more straightforward to assume that perceptual input is directly interpreted through the activation of LTM, and that manipulation of the images is achieved after transfer to the working memory system.

Neuropsychological dissociations

A second problem with the gateway view of WM is that damage to the gateway should result in impaired access to long-term memory (e.g. Della Sala & Logie, 2002). However, there is neuropsychological evidence that working memory can be damaged in the absence of an impaired long-term memory. The converse pattern of impairments, with damage to long-term memory coupled with an intact working memory, has also been described frequently. This double dissociation is difficult to explain with a model in which access to long-term memory could only be achieved via working memory. Some of the evidence for the double dissociation of impairments of short- and long-term memory was described in Section 1.2.1. Amnesic patients have been described with relatively spared short-term memory for various types of information (e.g. digits, words, locations and visual features), and there are patients demonstrating specific impairments in short-term memory, but normal access to long-term memory or long-term learning. In Section 1.2.1 only patients with this latter pattern of impairments in the verbal domain were described (e.g. Shallice & Warrington, 1970; 1974; Vallar & Baddeley, 1984a; 1984b; Vallar & Shallice, 1990). Some examples of patients with specific impairments in visuo-spatial working memory, coupled with intact visual object recognition will be described here, as well as patients with the opposite pattern of impairments. Special emphasis is placed on these impairments in the visual domain, as the experiments reported in this thesis focus on visuo-spatial working memory. If the visuo-spatial component of WM is damaged and WM would act as a gateway, then the transfer of visual information from the environment to LTM would be damaged. This would result in problems with visual perception such as object identification. The existence of a double dissociation of impairments of working memory and perception in the visual domain would thus provide more support for the view that perceptual input reaches long-term memory structures before being represented in working memory. Such a model would allow the possibility that LTM and WM can be damaged independently.

An excellent and comprehensive overview of neuropsychological impairments of visual perception and imagery is provided by Bartolomeo (2002). An example of a patient with impaired visuo-spatial working memory but relatively intact visual perception is reported by Manning (2000). Patient RG presented with an imagery impairment for object form and colour. He also had some problems recognising faces and objects, but his imagery impairment seemed to be much more profound than his perceptual deficit; he was unable to image items which he could still recognise. Sirigu and Duhamel (2001) reported on patient JB, who initially showed prosopagnosia and object agnosia, together with a complete inability to imagine the shape or colour of objects and faces and the form of letters. Later, however, the perceptual deficits disappeared, leaving a profound and isolated impairment of visual mental imagery. There is also an abundance of reports on patients with impaired visual perception, but preserved visuo-spatial working memory. Riddoch and Humphreys (1987), for example, described patient HJA, who had a dense visual agnosia, prosopagnosia and achromatopsia. Despite this, he was still able to draw from memory objects that he could no longer recognise visually. Another patient with profound visual object agnosia but intact visual imagery, CK, was described by Behrmann, Moscovitch, and Winocur (1994). This patient was also impaired in reading and recognising single letters. Despite his perceptual impairment, CK could produce detailed drawings from memory and showed preserved capabilities in an extensive series of visual imagery tasks. Similarly, agnostic patient ‘Madame D’ produced plausible drawings from memory, but was unable to identify her drawings on subsequent testing (Bartolomeo et al., 1998). She further performed perfectly on the object imagery tests and claimed to have vivid mental images. This dissociation was also present for orthographic material, and in the colour and face domains. A double dissociation in impairments of short- and long-term visual memory has furthermore been demonstrated in patients with selective deficits of immediate visual retention or of long-term learning for spatial locations (e.g. Vallar & Papagno, 2002).

Perceptual and representational neglect

The double dissociation in neuropsychological impairments of visual perception and visuo-spatial working memory is also well demonstrated in patients with hemispatial neglect syndrome. This condition will be described in more detail in this section, as Experiment 8 in this thesis investigated the processing of visual stimuli by neglect patients. In Section 9.2 an overview of the literature on implicit processing in neglect is given, and the neuro-anatomy of neglect will be discussed. Visual hemispatial neglect can occur isolated in the perceptual domain, or in the representational domain. Perceptual neglect is a failure to report, respond or orient to visual stimuli presented to the side opposite a brain lesion (usually the left side, following right hemisphere damage), when this failure cannot be attributed to either sensory or motor defects (Heilman et al., 1993). Patients with perceptual neglect have an intact visual system, but have severe deficits in visually perceiving their environment. At the same time, they have a completely intact ability to generate and maintain visuo-spatial representations in working memory (e.g. Della Sala & Logie, 2002; Logie, Beschin, Della Sala & Denis, 2005). Pure representational neglect patients, on the other hand, have a severe deficit in describing the contralesional side of mental images, but a completely intact ability to describe the scene currently in view (e.g. Beschin, Cocchini; Della Sala & Logie, 1997; Beschin, Basso & Della Sala, 2000; Bisiach and Luzatti, 1978; Coslett, 1997; Guariglia, Padovani, Pantano & Pizzamiglio, 1993).

That visuo-spatial working memory can be intact in patients with severe perceptual neglect has been demonstrated, for example, by Chokron, Colliot and Bartolomeo (2004). In their study, six perceptual neglect patients were asked to draw images with and without visual feedback. Whereas control participants draw objects in the same manner whether their eyes are open or closed, neglect patients draw more complete and symmetric drawings in the eyes closed compared to the eyes open condition. One interpretation of this finding is that in the condition with visual control, patients' attention was attracted by the right-sided details that they had just drawn, and consequently left-sided details were neglected. In the eyes closed condition, they would have relied on visual representations in working memory to make the drawings. This finding confirms that mental representations can be intact in perceptual neglect (Bartolomeo, 2002). Intact visual imagery in perceptual neglect patients is also demonstrated in a study by Denis, Beschin, Logie & Della Sala (2002). In this study, neglect patients were presented with novel layouts of familiar objects. In one condition, they saw pictures of four objects arranged in a two by two array, and had to report the presented objects and their location. In a second condition, the object array was left in view for a period of 90 seconds before being removed. The task was again to report the objects and their location, but this time relying on memory for the layout that had just been removed. In a third condition, patients were not shown anything, but were given an auditory verbal description of the object layout. In this case, the task was to report the objects and their location without any visual perceptual input. In the first condition, perceptual neglect patients tended to omit items that were presented on the left. This perceptual deficit led to a failure to report all left-sided items from memory in the second condition. However, in the third condition, when patients did not rely on perceptual input, the perceptual neglect patients reported items on the left as well as items on the right side. Again, this demonstrates an intact ability to generate and maintain visual images in working memory.

The performance of the perceptual neglect patients described by Denis et al. (2002) contrasts with the performance of a pure representational neglect patient. This patient performed at ceiling in the first condition, when reporting left- and right-sided objects from the layout in view. In the second condition, when reporting the layouts from memory, he reported items on the left less well than items presented on the right. Also in the third condition, when images had to be generated on the basis of verbal descriptions, performance was less well for items on the left than for items on the right. A number of patients with perceptual *and* representational neglect demonstrated the same bias in report of items from verbal input. Their representational neglect was thus independent of any visual perceptual input problems from perceptual neglect. These same patients showed no impairment in verbal recall of a list of random words presented aurally, indicating that their short-term verbal memory was intact. The results also indicate that the representational neglect patients do attempt to form a visual mental representation in what is clearly a damaged system, rather than that they rely on their intact verbal memory (Denis et al., 2002).

That the problems of representational neglect patients arise from a deficit in *storage* of images in visuo-spatial working memory, rather than from a failure to *attend to* the contralesional side of an otherwise complete mental image (e.g. Baddeley & Lieberman, 1980), was demonstrated by Logie et al. (2005). Two representational neglect patients (one of whom also demonstrated perceptual neglect) were presented with either a visual layout of four objects, or were given a verbal description of the layout, like in the Denis et al., (2002) study. In the verbal description condition, their task was to either recall the items from the layouts as they had been presented, or to report these as if they were from the opposite perspective to that presented. The pure representational neglect patient performed at ceiling in reporting the visually presented layout, whereas the other patient only reported the right-sided items from the layouts due to his perceptual neglect. In the verbal condition, control participants showed evidence of some forgetting overall, and lower performance in the reverse, than in the standard recall, but no evidence of any lateralised bias for items on the left or the right. Both patients reported items on the left less well than items presented on the right in the standard recall from verbal descriptions. When recalling items from the reverse perspective, again both patients showed poorer performance for items that were imagined on the left, even though these items were presented on the right, non-neglected side. Moreover, items that were presented on the left (and imagined on the right) were recalled equally well or better in the reverse condition than in the standard condition. Both patients had verbal memory spans that fell within the normal range. These results indicate that the representational neglect patients were able to undertake mental rotation of visual images successfully. Their recall performance of layouts created on the basis of verbal descriptions was dependent on the side of the mental image on which they based their recall. If representational neglect were a problem of directing attention to one side of a visual mental representation, some difficulty with mental rotation of the representation would be expected. The results suggest that this is not the case, and that image maintenance in visuo-spatial working memory is impaired in representational neglect (Logie et al., 2005).

The technique of asking representational neglect patients to report a visual layout or scene from memory was first used by Bisiach and Luzzatti (1978), although in their case the task required access to stored long-term knowledge rather than recently presented novel arrays as in the Denis et al. (2002) and Logie et al. (2005) studies. Bisiach and Luzzatti (1978) asked two representational neglect patients to imagine themselves standing in a very familiar scene (in their case the Cathedral Square in Milan, Italy) in a certain position (facing the Cathedral) and describe from memory what they could see. The representational neglect patients successfully reported details that would be on the right of the square from that viewpoint, but mentioned very few details from the left of the square. That this pattern of performance could not be attributed to a failure of long-term memory for details from one side, was demonstrated by asking the patients to do the same task, but now while imagining standing with their back to the Cathedral. From this opposite viewpoint, their performance was similar; they omitted details that were now on their left, but reported details that were now on their right and that they had omitted previously. The details that were now omitted on the left had previously been reported from the opposite viewpoint (Bisiach & Luzzatti, 1978). This basic paradigm is still used and developed further as a tool to assess representational neglect (e.g. Rode, Rossetti, Perenin & Boisson, 2004).

Cognitive theories about neglect

There has been much discussion in the literature about cognitive accounts of the deficits presented by neglect patients. The first theories advanced to explain the behaviour of perceptual neglect patients often regarded neglect as a disorder of gathering and processing sensory information (for review see Gainotti, 1993). It quickly became clear, however, that many patients with neglect simply do not have a visual field deficit, and it was unlikely that any kind of 'sensory' account could cope with the observations of pure representational neglect (Marshall, Halligan, & Robertson, 1993). The focus then started to shift to attentional theories of neglect. It is clear that perceptual neglect is a deficit in attention, and there are many different attentional accounts possible (for a review see Bartolomeo & Chokron, 2002). However, the study by Logie et al. (2005) indicated that representational neglect does not necessarily arise from an impairment of directing attention to mental visual representations. Another account that has been offered for neglect is the ‘representational account’, which holds that neglect is in essence a problem in the conscious representation of space. Due to a problem in spatial awareness, the mental visual representation of stimuli in the neglected visual field is impaired (e.g. Bisiach, Rusconi, Peretti, & Vallar, 1994). Bisiach (1993) suggested that in neglect there is damage to the cognitive system that holds information about the relationship between body parts and objects in the visual scene. He suggests that neglect could be characterised as damage to this system like a ‘torn mental screen’. This account regards the problems in attention as a secondary consequence of the problems in spatial representation. Also Driver & Vuilleumier (2001) proposed that neglect is caused ultimately by the damage of neurons that selectively represent certain parts of space for specific functions. If the representation of left space is weakened or absent, attention may not be directed to left space. However, this representation view of neglect cannot explain why perceptual neglect patients are still able to have a complete mental representation of scenes from memory. A lack of one coherent account for neglect has led researchers to argue that it is misleading to think of neglect as a single form of disorder. Not one cognitive theory of neglect has been able to account for the entire spectrum of clinical manifestations. It has been argued that each case may require a specific cognitive explanation with its own set of neuropathological correlates (e.g. Halligan & Marshall, 1992).

The workspace model of working memory, however, appears to be able to give exactly such a coherent account for both perceptual neglect and representational neglect, by combining attentional and representational theories. In the workspace model, perceptual neglect could be interpreted as a condition in which an attention deficit results in an impaired activation of long-term memory by perceptual input from the left side of the visual world. The asymmetry in the levels of LTM activation would then be passed on to the visuo-spatial component of working memory, for the on-line representation of the information. This would explain why perceptual deficits are often associated with representational deficits (e.g. Beschin et al., 1997; Della Sala & Logie, 2002). Perceptual neglect in the absence of representational neglect could be interpreted as the intact ability of perceptual neglect patients to directly retrieve information from LTM to WM, which is independent of processes of perception. In pure perceptual neglect patients, the representational system of WM is thus completely intact, but it has to deal with the unilaterally impoverished perceptual input. These patients thus show deficits in visual WM tasks that rely on perceptual input, but not on visual WM tasks that rely on visual representations from the long-term knowledge base (see Denis et al., 2002; Logie et al., 2005). Representational neglect, on the other hand, could be interpreted as an impairment in the generation or maintenance of visual representations in WM (e.g. Della Sala & Logie, 2002; Logie, 2003). Activation of LTM information driven by visual sensory input is still intact – as demonstrated by their unimpaired perception – as well as visual attention and long-term memory for visual knowledge (e.g. Denis et al., 2002; Logie et al., 2005). The existence of pure perceptual and pure representational neglect can thus be accounted for well by the workspace model, in which perceptual information activates LTM directly, and in which WM is seen as a separate workspace that deals with this activated information.

In contrast, the gateway model cannot easily explain the double dissociation in perceptual and representational neglect, nor the other double dissociations in impairments of perception and working memory in the visual and verbal domains. Deficits in visual working memory (i.e. visual imagery) should, according to the gateway view, go hand in hand with a deficit in the visual perceptual domain, as a result of the role of WM as a gateway for perceptual information on its way to the knowledge base. The data described here, however, demonstrate that access to visual long-term memory and the temporary retention of visuo-spatial information can be impaired independently. The results are rather consistent with the workspace model in which the representational system is separate from the perceptual system.

Implicit semantic processing

The gateway model encounters a third problem when trying to explain the wide range of evidence suggesting that semantic representations can be activated by visual perceptual input, without a conscious visual image of this input being available in the WM system; something that would be impossible if access to LTM were only possible through WM (see Cowan, 1988; Della Sala & Logie, 2002; Logie, 2003). Such evidence comes from studies investigating the effects of implicitly perceived perceptual stimuli. The effects of unconsciously perceived stimuli may be almost as varied as those of sensory information that does enter consciousness. They include physiological responses, such as brain activity or production of electrodermal responses, but also behavioural responses, such as changes in sensory threshold, effects on memory, and influences on various types of higher-order decision-making tasks (Dixon, 1981; Weiskrantz, 1997). Implicit perception can occur when a neuropsychological condition prevents stimuli from being perceived or processed consciously. For example, it has been demonstrated that there is unconscious lexical access in severely aphasic patients, procedural and motor skill acquisition in amnesics, implicit learning in amnesics, implicit face recognition in prosopagnosics and implicit object knowledge in agnosics (for review see Faulkner & Foster, 2002). Another example of implicit perception in a neuropsychological condition is the unconscious processing of visual information in the affected visual field of perceptual neglect patients. Experiment 8 in this thesis investigated implicit semantic processing of visual stimuli by neglect patients (see also Section 9.2).

Implicit visual perception also occurs in healthy individuals when material is presented below a perceptual threshold (subliminally) or when it is masked. There are several steps in normal visual information processing, each requiring different levels of perceptual and cognitive efforts and of attention. Early stages of visual analysis are associated with, for example, detection of elementary visual features (e.g. colour, line orientation and location) or figure-ground segregation. Later stages concern the more detailed analyses which eventually lead to recognition of objects. There is now substantial evidence that implicitly perceived visual stimuli can still activate semantic representations in long-term memory and be processed to the level of object recognition. For example, several studies have demonstrated priming of lexical decisions by the semantic content of subliminally presented (or masked) visual stimuli (for a review see McNamara, 2005). In a study by Naccache and Dehaene (2001), for example, participants were told that they would see a target number between 1 and 9, and had to indicate whether this number was smaller or larger than 5. Masked subliminal number primes were presented just before the target numbers. Participants were not informed about these primes, but were told that they would see a visual signal to announce the presentation of the target number. Half the trials were congruent (prime and target falling on the same side of 5, and hence promoting the same response) and half were incongruent. Participants were asked to perform a forced-choice prime comparison task after the experiment, to assess awareness for the primes. In this task, they were instructed to pay attention to the masked signal and to try and compare the prime number to 5. A significant priming effect was found: participants responded faster in the congruous condition than in the incongruous condition. Moreover, an effect of the semantic (numerical) distance between prime and target was observed: reaction time decreased when the semantic distance decreased. None of the participants reported having perceived the masked primes, and they performed at chance in the forced-choice prime comparison task. The priming effects occurred independently of the notation used for displaying the prime and target (Arabic digits or spelled-out words), thus confirming that they arise from a notation-independent semantic level. This experiment thus provides strong evidence for semantic processing of masked primes (Naccache & Dehaene, 2001). In another study by Draine and Greenwald (1998), participants had to perform two semantic classification tasks for visually presented words, one involving classification of pleasant vs. unpleasant, the other a name gender-classification task. Before the target word, a (masked and subliminal) prime word was presented that was either evaluatively polarised or was a male or female first name, in the consequent classification tasks. Congruent trials were those in which the prime and target were both in the same category (i.e. both pleasant, unpleasant, male or female), and incongruent trials were those in which one of the prime-target pair was pleasant and the other unpleasant for evaluative classifications, and one of the pair was male and the other female for gender classifications. Awareness for the primes was measured by asking participants to perform a forced-choice comparison task, judging whether the prime stimulus was a word or a string of alternating Xs and Gs. Stimuli in this task were identical to those used in the semantic classification tasks. Words (or names) and XG strings appeared equally often. In a series of 4 experiments using these same tasks but with different parameters (e.g. response window time and inter-stimulus intervals) a replicable semantic priming effect was found for both evaluative and gender classification tasks; participants responded faster in the congruent conditions. Performance on the indirect priming tasks was always significantly better than performance on the forced-choice direct (awareness assessment) tasks (Draine & Greenwald, 1998). Semantic processing of unconscious stimuli has thus been demonstrated reliably in priming studies, using different types of stimuli and tasks.

The fact that semantic information about visual stimuli appears to be available even when these stimuli have not been consciously perceived, suggests that LTM (the semantic knowledge base) has been activated, without the stimuli being represented in WM (e.g. Della Sala & Logie, 2002; Logie, 1995; 2003). The suggestion that these stimuli are not part of visual WM, stems from the fact that WM has repeatedly been associated with conscious awareness (e.g. Baars, 2003; Baddeley, 2000). The gateway model could only account for findings of implicit semantic processing by assuming an extra fast-track in the model from perceptual input directly to LTM, bypassing WM (Della Sala & Logie, 2002). This 'leaky gateway' model proposes in essence that some perceptual input has direct access to WM, and some has direct access to LTM. Such a model, however, is less parsimonious than the workspace model, in which all perceptual input access LTM first. The phenomenon of implicit processing can be accounted for more readily by the workspace model, in which perceptual input activates representations in LTM directly, and prior to this activated material being made available in the WM system. Implicit semantic processing of visual stimuli would then reflect the activation of LTM, combined with a failure (due to impoverished or degraded perceptual input) to generate a conscious image in WM. The activated LTM traces are sufficient, however, to influence behaviour.

Summary

This section discussed a number of fundamental problems with the gateway view of perceptual input directly accessing the WM system before activating representations in LTM. If images in visual WM were derived directly from perceptual input, these images would be raw sensory images consisting of shapes, lines and colours. This view is inconsistent with the experimental evidence suggesting that visual images in WM, derived from perceptual input, are identified and interpreted on the basis of information in LTM (e.g. Barquero & Logie, 1999; Chalmers & Reisberg, 1992; Logie, 2003). The gateway model also has difficulty accounting for the double dissociation of impairments of perception and working memory, described in both the visual and verbal domain. Especially problematic are the isolated impairments of visual or verbal working memory, without any deficits in perception, long-term learning or retrieval from LTM (e.g. Vallar & Baddeley, 1984; Denis et al., 2002). If LTM could only be accessed through WM as a gateway, and this gateway were impaired, access to LTM would be expected to be impaired as well. Finally, the phenomenon of semantic processing of implicitly perceived stimuli presents a problem for the gateway model. The activation of semantic representations by stimuli that remain unconscious could be interpreted as the activation of LTM without a representation of the stimuli in visual WM. The gateway model would have to be extended to be a ‘leaky gateway’ to account for the data on implicit processing, with an extra fast track for perceptual input directly to LTM. This would make the model less parsimonious than the workspace model. The next section will describe similar problems of the unitary model.

1.4.2 Problems with the unitary model

Like with the gateway model, there are some fundamental problems with the unitary model of the interaction between WM and LTM. These problems stem from theoretical considerations of the concept of seeing WM as activated LTM, from neuropsychology, from neuro-imaging studies and from experimental psychology. These problems will be discussed in detail in this section.

Theoretical considerations

A rather theoretical conceptual problem with the unitary model concerns its simplicity, of seeing WM as activated LTM. This simplicity has been argued to make the model straightforward and parsimonious compared to models that assume a separate multi-component WM (e.g. Ruchkin et al., 2003), but is regarded as misleading by some researchers. Several researchers have argued for example, that the unitary model might be too simplistic to account for the range of complex processes that WM is held responsible for. Baddeley (2003b), for example, argued that the interactions between WM and LTM are too complex for the simple interpretation that WM is activated LTM material. Logie and Della Sala (2003) have argued that WM retention as activated LTM fails to account for the interaction between processing and storage, which is an important property of the concept of WM. They argue that one advantage of the multi-component working memory concept is that it incorporates both on-line processing and temporary memory (e.g. Baddeley & Logie, 1999), allowing the concept of WM as a mental workspace (e.g. Logie, 1995; 2003), rather than as a simple temporary storage device. In their eyes, the unitary view fails to capture, or to account for, this concept of orchestrated processing and storage (Logie & Della Sala, 2003). Olson et al. (2006b) have furthermore warned that a strong version of the view of WM as activated LTM would render WM tantamount to consciousness or attention (see e.g. O'Reilly, Braver & Cohen, 1999). Another criticism that has been raised against the simplistic unitary view is that it is so general that it becomes theoretically sterile, unless an attempt is made to specify in detail the processes involved (e.g. Baddeley, 1996; Logie & Della Sala, 2003).

It thus appears that, in fact, the unitary model is not that simplistic, and that the view of WM as activated LTM requires many additional assumptions and theoretical processes to account for the data (e.g. Cowan's focus of attention, awareness level of activation, external executive control processes, etc). Even then, the model would still have difficulty accounting for a range of cognitive processes, such as the binding and maintenance of input from different modalities, retention of ordinal position of items, the manipulation of the activated information, temporary retention of the novel results of those manipulations, and dual-task interference (Logie & Della Sala, 2003). The importance of a WM model that can account for the capacity to manipulate and create new representations on a temporary basis, rather than simply activating old memories, was also emphasised by Baddeley (2003).

The imaging data are not conclusive

In Section 1.3.2 a brief summary was given of results from neuro-imaging studies that have been taken as evidence for the unitary view of memory. These studies revealed that there is an overlap in activity of brain regions involved in perception, working memory retention and retrieval from long-term episodic memory (e.g. Postle, 2007; Ruchkin et al., 2003). The main finding that emerged from these studies was that the same posterior LTM systems are associated with the initial processing of perceptual information as well as with temporary retention of this information in WM tasks. For working memory tasks there was additional activation of prefrontal areas. The prefrontal cortex was hypothesised to have a control function to maintain the LTM traces in an active state for temporary retention (e.g. Ruchkin et al., 2003). However, as briefly mentioned in Section 1.3.2, these data are not inconsistent with an interpretation in terms of an anatomically separate WM system. In their comment on the Ruchkin et al. (2003) article, Logie and Della Sala (2003) argue that there is nothing in the reviewed data that constrains the interpretation that temporary retention involves areas of the prefrontal cortex, in addition to some form of ongoing activation of the recently activated traces in LTM. A role of LTM in WM retention tasks would even be expected on the basis of, for example, the observation that there is an advantage of word lists over non-word lists in immediate serial- and free-recall tasks (indicating an involvement of semantic information in supporting the temporary retention). Logie & Della Sala (2003) emphasised that there is a different network of activation associated with temporary memory than with perception and LTM tasks, even if there is some overlap in the brain areas involved. They also suggest that the prefrontal cortex might even be the seat of temporary memory. In this view, representations in LTM (in posterior areas) become activated following perception of stimuli, and a broader network, including the prefrontal cortex, can be recruited to maintain the material and to manipulate it when required. This interpretation would be consistent with WM holding the products of activated traces from, and being functionally distinct from LTM (Logie & Della Sala, 2003).

Consistent with this latter interpretation are studies that have found anatomically different regions within the prefrontal cortex, responsible for different cognitive operations of WM (e.g. Braver et al., 2001; D'Esposito, Postle, Ballard, & Lease, 1999a; D’Esposito, Postle, Jonides, & Smith, 1999b; D’Esposito, Postle, & Rypma, 2000; Owen, Milner, Petrides, & Evans, 1996; Owen et al., 1998; 1999; Manoach et al., 1997; Petrides, 1996; Prabhakaran et al., 2000; Ranganath, Johnson, & D’Esposito, 2003; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999). The general pattern that emerges from these studies is that the ventrolateral prefrontal cortex (VL-PFC) appears associated mainly with WM maintenance, whereas the dorsolateral prefrontal cortex (DL-PFC) is recruited when there is an increased memory load or when manipulation of the material held in WM is required. These results fit less well with the suggestion that WM maintenance is strictly in posterior cortices, and that the role of the prefrontal cortex is only in maintaining these posterior areas in an activated state (e.g. Ruchkin et al., 2003). Moreover, some studies have found evidence for the presence of modality-specific memory stores in the VL-PFC; this region shows lateralised selective activation related to material-type (e.g. Braver et al., 2001; Smith & Jonides, 1997; D'Esposito et al., 1998; Wagner et al., 1998). The left VL-PFC appears to be selectively engaged during the processing of verbal items, whereas the right VL-PFC is selectively engaged during processing of visuo-spatial items. The observation that there are differential areas in the PFC implicated in the retention of different types of information is, again, less compatible with the suggestion that the PFC simply maintains material in LTM in an active state. These data rather suggest that the PFC has a more prominent role in WM, and indeed, could be the seat of WM, with specialised short-term stores for verbal and visuo-spatial material.

Another argument against the interpretation of the neuro-imaging data in terms of the view that WM comprises activated LTM, is the fact that an overlap in activation of brain areas for different tasks (i.e. LTM and WM tasks) does not necessarily mean that the same cognitive process is involved (e.g. Cabeza, Dolcos, Graham and Nyberg, 2002; Logie & Della Sala, 2003; Ranganath & Blumenfeld, 2005). In fact, Ruchkin et al.'s (1997) ERP study revealed that there is a temporal changing pattern of activation in a task involving the perception and consequent retention of visual or verbal stimuli (see Section 1.3.2). This could reflect different modes of operation of the same brain structures, and would thus mean that these areas are associated with different cognitive functions (Fuster, 1995; Logie & Della Sala, 2003). Cabeza et al. (2002) furthermore argued that an activation overlap for different tasks may also occur because the activated area comprises subregions differentially involved in each of the tasks. In support of this, they have demonstrated that different areas within the prefrontal cortex and posterior areas are associated either with LTM activation or with WM retention. They investigated episodic LTM retrieval with a word recognition test and WM with a word delayed-response test, using event related fMRI. Analysis of the activations revealed that the right dorsolateral PFC and bilateral anterior and ventrolateral PFC were more active during episodic LTM retrieval than during WM. In contrast, the left posterior/ventral PFC and bilateral posterior/dorsal PFC were more active during WM than during episodic retrieval. A similar dissociation in areas of activation was found in the lateral parietal cortex. Superior areas were involved in both episodic retrieval and WM, whereas a left inferior region was more involved in WM than in episodic retrieval (Cabeza et al., 2002). These results thus suggest that specific areas in the brain are specialised in WM maintenance, and that these areas are different from areas involved in LTM activation; an observation inconsistent with WM simply comprising activated LTM material.

Other studies that failed to replicate an exact overlap in activation for LTM and WM tasks are studies that looked at visual imagery. Some studies demonstrated that the same brain areas are involved in visual perception as are in visual imagery (e.g. Kosslyn et al., 1994). These data would also be consistent with the unitary view. Other studies, however, have found that different brain areas are activated during visual imagery tasks and visual perception tasks (e.g. Ganis et al., 2004; Mellet et al., 1995; 2000). Mellet et al. (2000), for example, recorded regional cerebral blood flow (rCBF) while participants performed a task that required visual mental imagery. Participants were asked to memorise 3D scenes that were visually presented or were based on a verbal description. There was no significant increase of rCBF in the primary visual cortex in the mental imagery conditions. This result suggests that visual WM is not dependent on the activation of areas that are involved in visual perception or LTM. These data are thus inconsistent with the unitary view of WM.

Overall, it thus appears that the evidence from neuro-imaging studies for the unitary view of memory is not very convincing. Some studies have failed to replicate the overlap in activation during tasks that involve perception, working memory retention and retrieval from LTM. Other studies have found evidence to suggest that when an overlap *was* found, this could be attributed to the association of specialised subregions with different cognitive functions. Specifically, the dissociation in activation patterns in prefrontal and parietal areas in LTM retrieval and WM tasks indicates that these are two anatomically separate cognitive functions. And, most importantly, the imaging data that have been taken as evidence for the unitary model can be reinterpreted to support the workspace view of WM. The interpretation of the neuro-imaging data remains debatable, however, with two contrasting views: one of the prefrontal cortex supporting working memory storage during delay periods, and one of prefrontal regions being involved only in extra-mnemonic executive control operations (see also Postle, Druzgal, and D'Esposito, 2003). It appears that neuro-imaging data alone cannot resolve this debate, and the interpretation should be driven by additional data from independent neuropsychological and behavioural experiments.

Neuropsychological data

Like the gateway model, the unitary model of WM has difficulty accounting for the wide range of neuropsychological data demonstrating that LTM and WM can be impaired independently of each other. If verbal short-term memory representations are activated verbal long-term memory representations, then deficits in verbal short-term memory for specific types of representations should be indicative of impairments in accessing or establishing long-term memories for those representations. As discussed, in the classical cases in literature this is not the case (e.g. Shallice and Warrington, 1970; Baddeley, 1984a; 1984b; see also Sections 1.2.1 and 1.4.1). The same argument applies to impairments of WM in the visual domain. The reports of patients with selective impairments of visual working memory (e.g. representational neglect patients) present a problem for the unitary model (e.g. Della Sala & Logie, 2002). The converse pattern of impairments, with a selective deficit in LTM coupled with intact WM, would be equally difficult to account for by the unitary model. If WM were simply activated LTM, and LTM was impaired, then WM would be expected to be affected as well. This is inconsistent with the data suggesting that short-term memory for a range of different types of material is relatively intact in patients with dense amnesia (e.g. Cave & Squire, 1992; Hamann et al., 1995; Olson et al., 2006a; 2006b; see also Section 1.2.1). In an attempt to account for these data, Cowan (1999) has argued that long-term memory deficits are not necessarily due to damaged stores. Rather, such deficits could be due to impaired processes of simultaneous activation across long-term stores that lead to an episode being stored. This would, however, only account for anterograde amnesic patients. Ruchkin et al. (2003) questioned the evidence for a dissociation between working memory and long-term memory impairments. They cited a report by Romani and Martin (1999) describing individuals with a semantic short-term memory deficit, who also have problems forming semantic, but not phonological long-term memories. In contrast, individuals with a phonological short-term memory deficit show the reverse pattern of difficulty. They argued that when the nature of representations is taken into account, the neuropsychological evidence rather supports the idea that short-term memory is activated long-term memory. However, the observations of Romani and Martin (1999) are not inconsistent with a view of separate short- and long-term memory stores (see e.g. Vallar, 2003). In fact, models that do propose separate modality-specific stores for short-term memory do assume that working memory plays an important role in the long-term learning of information (e.g. Baddeley, 2003a; Logie, Engelkamp, Dehn, & Rudkin, 2001).

Not only neuropsychological evidence for the functional separation of working memory and long-term memory present a problem for the unitary model. Also neuropsychological evidence for the existence of modality-specific short-term memory stores is difficult to handle by the unitary model. The unitary model assumes a single storage component (long-term memory) coupled with a general purpose attentional controller (e.g. Cowan, 1988; Cowan et al., 2007; Engle, 2002). The multi-component working memory model (Baddeley & Hitch, 1974; 1994) was developed on the basis of neuropsychological evidence that supported the existence of specialised verbal and visuo-spatial stores and rehearsal mechanisms (some of these data were reviewed in Section 1.2.3). The presence of patients with selective impairments of one of the proposed components with relative sparing of the other components is more difficult to account for by the unitary model.

Experimental data

One argument for the unitary view of memory was based on the observation that STM and LTM are associated with similar memory phenomena, and that it is therefore redundant to postulate two different systems (e.g. Crowder, 1993). One such phenomenon that was thought to be associated with both STM and LTM was long-term learning, like the Hebb effect (Hebb, 1961, see Section 1.3.1). More recently, however, researchers have failed to replicate this finding in the visual domain. Treisman (2006) argued that if WM is the activated subset of LTM, one might expect any relevant learning to show up in both (Treisman, 2006). In her experiments, she explored the possibility that WM would benefit from long-term learning of contingencies between visual properties, so that consistent property bindings would provide facilitation also when tested in WM paradigms. Participants were presented with an array of five coloured shapes in a change detection paradigm for which they had to attend to one stimulus property (either colour or shape). Some combinations of colour and shape were much more frequent than others, creating consistencies between the two properties. In a surprise test after the experiment, long-term learning of these contingencies was tested in an explicit recall task. Whether any long-term learning was also expressed in WM was tested by looking for dependencies between colour and shape during the experimental trials. Treisman (2006) argued that if the predictable pairings were represented in WM as well as LTM, WM performance should be better with associated pairs than with random pairings. Results revealed that participants did show learning of the consistencies across trials in the LTM recall test. They achieved a mean accuracy of 65% in the shape-relevant condition, and of 36% in the colour-relevant condition. Chance probability of selecting a correct pairing was about 15%. However, there was no benefit of this long-term learning of contingencies in WM recognition. Additionally, performance of participants who received associated pairs was not higher than performance of participants for whom colours and shapes were randomly combined. Therefore, in this experiment there was no evidence for any consistent use of long-term contingencies in the WM task. If WM were activated LTM, one would expect this long-term learning to be expressed in WM as well. Moreover, further analyses revealed different processes of binding in WM and LTM. Treisman (2006) concludes that although their data do not yet rule out the unitary view of memory, their results fit better with the view of WM as separate, differentially specialised stores than with the activated LTM view.

Other empirical studies that have provided evidence against the unitary view are studies of dual-task performance. These studies have often demonstrated that with some combinations of tasks, healthy adult participants can perform two demanding tasks simultaneously with no or very little decrease of performance on these tasks compared to control levels (e.g. Baddeley & Logie, 1999; Della Sala, Baddeley, Papagno, & Spinnler, 1995; Duff & Logie, 2001; Logie, Cocchini, Della Sala & Baddeley, 2004). In the multi-component WM model, such dual-task performance can be easily accounted for in terms of the specialised components for maintaining and manipulating verbal and visuo-spatial information (the phonological loop and visuospatial sketchpad), combined with a separate attentional controller (the central executive) (Baddeley & Logie, 1999; see Section 1.2.3). The different tasks could then be argued to selectively rely on the different subcomponents. The unitary model would have more difficulty accounting for these data. In this model, temporary retention and processing are both assumed to require a limited capacity attentional system (e.g. Cowan, 1988; Cowan et al., 2007; Engle, 2002). Cowan (1988) specifically proposes that there is a limited pool of processing capacity that can be allocated to different tasks. The amount of capacity needed for any particular task depends on the difficulty of the particular operations being carried out. Whereas in Baddeley's model storage of information takes place in separate buffers and processing takes place through separate executive control processes, Cowan's model holds that the focus of attention also serves as a storage device. This model would therefore predict that when there is a strong executive processing demand, it is likely that there is interference with storage (in particular, by pushing stored information out of the focus of attention) (Cowan, 2005). The conflict between storage and processing of information need not be complete, for example when processing can become automatic with practice. Also, some types of information can be stored within activated portions of LTM without being in the focus of attention (Cowan, 2005). Nonetheless, with only one limited capacity attentional process responsible for both retention and processing, it is substantially more difficult to explain resistance to dual-task interference where both tasks are set at levels that are extremely demanding for the individual (e.g. at span for each task performed separately). Cowan (2005) explains domain-specific interference in terms of conflicting memory codes. He assumes that the central executive does not have domain-specific pools of capacity, and that domain-specific interference occurs because of conflicting memory codes rather than conflicting executive operations; activated representations of two or more stimuli with similar features tend to interfere with one another within the activated portion of memory (Cowan, 2005).

Cocchini, Logie, Della Sala, MacPherson & Baddeley (2002) directly tested the multi-component model against the unitary model by investigating the effects on performance of combining different memory and processing tasks. The unitary model would predict substantial interference between any two tasks that require either processing or retention of information, whereas the multi-component model would only predict interference between two tasks that would draw on the same subcomponent of the WM system. They found that a perceptuo-motor tracking task during a retention interval resulted in no disruption of a verbal digit memory task (over and above the impact of a delay in recall), and showed only minimal disruption of a visual matrix pattern memory task. Furthermore, a verbal memory task in the retention interval of the visual task (or vice versa) was found to have virtually no impact either. However, the verbal memory task (but not the visual memory task) was significantly disrupted by articulatory suppression in the retention interval. In the multi-component model, the verbal memory task is assumed to rely on the phonological loop component, whereas the visual memory task relies on the visuospatial sketchpad. These domain-specific temporary retention systems can act in concert with little mutual interference. The perceptuo-motor tracking task could be argued to rely mainly on the central executive component, whereas articulatory suppression engages the articulatory rehearsal system of the phonological loop. This could explain the lack of considerable interference effects of all combinations of tasks, and the impact of articulatory suppression on the verbal memory task (Cocchini et al., 2002). Cowan's model could possibly account post-hoc for the combinations in which participants were given a memory preload followed by a period in which they performed a memory task or perceptuo-motor tracking. In these cases, the memory preload could have been in the activated long-term memory portion but outside the focus of attention (and therefore subject to decay). The central executive could then have been directed at the interpolated task. During delayed recall, attention is then focussed on retrieving items from decaying traces, leading to an impact of delayed recall, but no further substantial impact on memory from the interpolated task. However, Cowan's model runs into difficulty when trying to account for the greater impact of perceptuo-motor tracking on the visual memory task than on the verbal memory task. There is no reason to expect that motor control would involve codes that overlap with those used for retaining a visuospatial pattern. The multi-component model could explain this specific effect on the visual memory task in terms of the role of the visuo-spatial sketchpad in the enactment of physical movement (e.g. Logie, 1995; Logie et al., 2001).

Cowan's model also meets a significant challenge when attempting to account for a lack of dual-task interference when any two very demanding tasks are performed simultaneously (Cocchini et al., 2002). In a more recent study, Morey and Cowan (2005) attempted to demonstrate cross-domain interference between verbal and visual material in working memory; an effect that would be expected if there is a central form of storage, like the focus of attention (Cowan, 2001). They interpolated a verbal digit memory task in a visual pattern memory task, but found no effect of the digit task on performance on the visual task, when no specific instructions for verbal rehearsal were given. There was no difference in visual task performance between this (presumably silent rehearsal) condition and a control condition in which no interpolated verbal task was given. When participants were required to rehearse the digits of the verbal task out loud, there was a decrease in performance on the visual task. However, when no rehearsal instructions were given, and an additional simple aloud articulatory suppression task was required, there was, again, no interference. These results are largely consistent with Cocchini et al. (2002), in that the concurrent performance of two demanding tasks does not seem to lead to a significant decrease in performance on either of the tasks. Even though Morey and Cowan (2005) conclude that a general attentional resource is needed to maintain items in working memory on the basis of these findings, their results rather speak in favour of the opposite view, of maintenance in the two modalities not sharing much in terms of resources.

Cocchini et al. (2002) discuss another important disadvantage of Cowan's model compared to the multi-component working memory model. One consequence of the assumption that interference effects arise from similarities among the material or among the memory codes involved in the two tasks, is that often similarity may be determined only post hoc, with the interpretation arising from the data pattern rather than a theoretically motivated prediction. The multi-component approach is much better suited to make specific predictions about interference a priori, on the basis of a wide range of data patterns, and drawing on not just differences in codes employed but also on neuropsychological double dissociations and dissociable patterns of brain activation associated with the different components. In this context, an account based on differences or similarities among codes used to support task performance, even if it were not post hoc, has much more limited explanatory utility. The next section in this chapter will focus more on the interpretation of dual-task performances in terms of the three models of the interaction between working memory and long-term memory. Experiments 1 to 7 described in this thesis also employed dual-task techniques to compare the models.

Summary

In this section, a number of observations and arguments that are inconsistent with the unitary model are reviewed. The first is a rather theoretical argument, focusing on the simplicity of the model. It has been argued that the model is too simplistic to account for a range of complex cognitive processes, and that many extra assumptions have to be made to account for the data (e.g. Baddeley, 2003b; Baddeley & Logie, 1999; Logie & Della Sala, 2003). Secondly, neuro-imaging studies do not provide conclusive evidence for the unitary model. The neuro-imaging studies taken as support for the unitary view can be reinterpreted to support the workspace view of working memory (e.g. Logie & Della Sala, 2003). Thirdly, there is a large body of neuropsychology data that is inconsistent with the unitary view, such as studies demonstrating that working memory and long-term memory can be impaired independently (e.g. Della Sala & Logie, 2002; Vallar & Baddeley, 1984), and studies demonstrating that there are modality-specific short-term stores that can be impaired selectively (e.g. Logie & Baddeley, 1999). Finally, there are some experimental data that are inconsistent with the unitary model, such as Treisman's (2006) demonstration that long-term learning effects did not carry over into short-term memory tasks, and Cocchini et al.'s (2002) demonstration that participants can perform remarkably well under demanding dual-task conditions.

1.4.3 Merits of the workspace model

The workspace model emerged from the process of finding a solution to the problems of the gateway and unitary models. Perhaps the main problem of both the gateway and unitary model is their difficulty to account for the range of neuropsychological patient data suggesting that WM and LTM can be impaired independently of each other. In both models WM and LTM are seen as crucially dependent on each other. The workspace model differs fundamentally from the other two models in this respect. It still proposes a close link between WM and LTM, but at the same time regards WM and LTM as two anatomically and functionally separate systems, with WM being a system dealing with the activated contents of LTM. In doing so, it offers a better account for the patient data, while maintaining the explanatory power of a multiple-component model and the notion that the contents of WM comprise activated information from LTM. The workspace model is also able to account for other data that the gateway and unitary models have difficulty with, such as the fact that the contents of WM are identified objects, the phenomenon of implicit processing, and the imaging data suggesting that different areas of activation are associated with WM than with LTM tasks.

One critical remark against the workspace model, expressed by Baddeley (2007), is that the view of all perceptual input having to pass through LTM before reaching WM seems to imply a strict serial flow of information, although in the opposite direction of the gateway model. Fixed serial processing in either direction seems simplistic. It also implies that even new information, for which there are no representations in stored knowledge, has to pass through LTM. Yet we are able to look at new objects, for example, that we have never perceived before, and hold an image of this in WM. A possible explanation is that information is never completely new or unfamiliar. There are always aspects of it which can be interpreted or recognised, and for which there are traces in previous stored knowledge that can be activated. Fuster (2003) has argued that perceiving involves the matching of external gestalts to internalised representations in LTM. He argues that there cannot be an entirely new percept, because any conceivable new sensory configuration will activate other representations in long term storage on basis of associations of similarity or contiguity. Also Kroger (2003) proposes something similar. He says that it could be argued that elements of a novel to-be-remembered shape (e.g. corners, curves, etc.) are retained by invoking neural representations of these features learned over time, thus perhaps constituting long term memories bound in the current episode into the novel shape. He thus essentially argues that the content of WM is a binding of long term memories and that the binding of features in WM together constitute a new representation (Kroger, 2003). Logie (2003; Logie, Engelkamp, Dehn, & Rudkin, 2001) furthermore argues that where the activated information from the knowledge base is incomplete, WM acts as the workspace to manipulate the information and to seek some means to resolve ambiguities or generate new knowledge. He argues that it is an important property of WM to generate new knowledge from old in case of manipulation and transformation within WM of traces of activated LTM material. This, he proposes, could be one possible reason why we have evolved with a WM system. Manipulation within WM might be the mechanism by which we acquire knowledge from birth (Logie, 2003; Logie et al., 2001).

1.5 COMPARING THE THREE MODELS EXPERIMENTALLY

The three models of the relationship between WM and LTM are still all prominent in current research, even though there are substantial differences between them, and there are clear problems with the gateway and unitary models. However, there have not been any extensive empirical tests of the workspace model in healthy adults. Most of the support for this model arises from observations of selective impairments in brain damaged individuals. Some empirical support for the workspace model from studies with healthy participants has come from the areas of mental discovery and creativity, and mental synthesis. As reviewed in Section 1.4.2, there have been a few experimental efforts to contrast the unitary model with the multi-component WM model (e.g. Cocchini et al., 2002; Treisman, 2006). These attempts remain very scarce, however, and there have been no studies that have explicitly addressed the contrasting assumptions between all three models using experimental techniques. One area of research in experimental psychology has, however, provided a way to compare the models indirectly. The three models make different predictions about interference of secondary tasks with visual working memory tasks. There is a relatively large body of literature on interference in visual working memory, even though these studies were usually aimed at investigating functional and structural properties of visual working memory itself. Research has focused much on the effects of irrelevant visual input on visual short-term memory, and visual imagery tasks. It has become clear from these studies that irrelevant visual input selectively disrupts imagery, but not visual short-term retention tasks. Reinterpreting the results from these studies in terms of the three models of information processing in the perceptual and memory system can indirectly test the assumptions and predictions of the models. In the next sections a review of the literature on interference in visual working memory will be given, followed by a discussion of the results in the context of the gateway, unitary and workspace model. Experiments 1 – 7 in this thesis aimed to compare the three models directly by testing their predictions about interference in visual working memory, drawing on the previous findings in this literature.

1.5.1 Interference with visual working memory

Disruption of visual imagery

Irrelevant visual input has been found to interfere with a range of different visual imagery tasks. An often used imagery task is the pegword mnemonic, a visual memory technique involving the generation of interactive images in order to remember a list of words. In this task, participants first learn a list of cue words that are associated (by rhyme) with the numbers one to ten (e.g. one-bun, two-shoe, etc). In the encoding phase of the task, participants have to generate interactive images of presented target words with these cue words. In the retrieval phase, participants are presented with the cue words, and have to recall the target words. The encoding and retrieval phases of this task thus involve the (re)generation of images in visual working memory, on the basis of representations in long-term memory, whereas the retention phase involves the maintenance of these created images. The encoding and retrieval phases of the pegword mnemonic task have been demonstrated to be disrupted by various tasks, such as viewing visual matrix patterns (Logie, 1986), plain coloured squares (Logie, 1986), a dynamic visual noise (DVN) display (e.g. Andrade et al., 2002; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996a; 1996b, 1999, 2006), a moving dot (Quinn & McConnell, 1996a), a colour matching task (Zimmer & Speiser, 2002) and a series of (abstract or concrete) line drawings (Andrade et al., 2002; Logie, 1986; Quinn & McConnell, 1996b).

DVN has also been demonstrated to disrupt other imagery tasks, such as visualising a route on a previously learned climbing wall (Smyth & Waller, 1998), an animal size comparison task (Dean, Dewhurst, Morris, & Whittaker, 2005), making true-false judgements about imagined objects or scenes (Dewhurst, Dean & Whittaker, 2004), and the 'method of loci' (Quinn & McConnell, 1996b). This last task is a technique to remember a word list by imagining the objects located in a very familiar environment (e.g. one's house) and then mentally going through the environment at recall. All these tasks depend crucially on the generation of mental images in visual working memory from representations in LTM, and DVN was presented during this generation process. Taken together, the data thus suggest that irrelevant visual input interferes with the process of generation of images in visual working memory on the basis of activated LTM representations.

Another observation of the impact of irrelevant visual input on imagery was made by Baddeley and Andrade (2000). They presented participants either with novel visual patterns (presented stimuli) or with a written description of a scene e.g. “a child picking flowers” (cued stimuli). Participants were instructed to create a mental image of these stimuli and keep the image in mind for a period of 6 seconds. They were then required to rate the vividness of their image. During the 6 seconds participants were presented with a DVN display or with a control white screen. DVN had an effect on the rated vividness of the image for both types of stimuli (presented or cued), but the effect was stronger with the cued stimuli (Baddeley & Andrade, 2000). Participants were specifically instructed to try and keep the image actively in mind, and were motivated to attempt to experience their images vividly. This may have led participants to continue reactivating their mental representations during the 6 seconds. Because the cued stimuli images are generated from visual representations in LTM, this means that participants may have continued to activate LTM material during the 6 seconds. Therefore, these results add to the evidence to suggest that irrelevant visual input interferes with the generation of images in an imagery task.

No disruption of visual short-term memory

In contrast to the evidence that irrelevant visual input interferes with visual imagery, visual short-term memory appears to be relatively insensitive to the effects of irrelevant visual input. Some researchers have, for example, found that the retention phase of the pegword mnemonic is resistant against disruption by irrelevant visual input. Quinn and McConnell (2006) presented DVN selectively during the encoding, retention and retrieval phases of the pegword mnemonic task and only found an impact of DVN during encoding and retrieval, not during retention. Also Zimmer and Speiser (2002) presented DVN only during the retention interval of the pegword mnemonic and found no effect on recall performance. It has to be said, however, that Zimmer and Speiser also failed to replicate the effect of DVN on the encoding phase of the pegword mnemonic. The retention phase of this task could be seen as essentially a visual short-term memory task. The images that are generated in the encoding phase are stored, and recalled in the retrieval phase. The retention phase does not involve any interaction with long-term memory, or any further processing.

Additionally, DVN has been shown to have no effect on short-term memory for visual patterns (Andrade et al., 2002; Avons & Sestieri, 2005; Zimmer & Speiser, 2002) or for unfamiliar Chinese characters (Andrade et al., 2002). In Baddeley and Andrade's (2000) experiment described above, there was an effect of DVN on vividness ratings of mental images, especially those generated on the basis of LTM. However, DVN had no effect on recognition memory performance of the novel visually presented stimuli (i.e. visual patterns) in the same experiment. Baddeley and Andrade speak about the 'imagery phase' of the experiment, when referring to the 6 seconds retention interval of the task. However, in case of the visual patterns, the retention phase only involved maintaining the patterns, even though participants were instructed to try and assess the vividness of their mental images. Therefore, the task with the presented stimuli may be better described as a visual short-term memory task than as a visual imagery task.

The effects of irrelevant visual input are selective

Some studies have suggested that the impact of irrelevant visual input on visual imagery but not on visual short-term memory cannot be attributed to imagery somehow being more demanding or difficult than short-term memory. Dean et al. (2005), for example, demonstrated disruption of a mental size comparison judgment task by DVN but not by irrelevant speech. Logie (1986) demonstrated that irrelevant line drawings disrupted the pegword mnemonic, but did not disrupt verbal memory based on rote rehearsal (a verbal technique to remember word lists). Irrelevant speech, however, did not have any effect on the pegword mnemonic, but selectively disrupted the rote rehearsal technique. The impact of irrelevant visual input on the imagery task can thus not be explained by arguing that the imagery task is demanding or difficult and would be disrupted by any secondary task. In that case, the irrelevant speech should have disrupted the pegword mnemonic as well. The results rather point towards a selective interference effect of the visual input on the visual imagery task, and of the verbal input on the verbal memory task. Quinn and McConnell (1996b) replicated this double dissociation of interference effects of irrelevant visual input (DVN in their case) on the pegword mnemonic and of irrelevant speech on rote rehearsal. Quinn and McConnell claimed that the effect of irrelevant pictures on visual processing is more likely to be general rather than selective. They argued that the regularly changing aspect of irrelevant concrete drawings engages general attentional mechanism. This would not be the case for DVN, because the change here is constant and evenly distributed throughout the display (Quinn & McConnell, 1996b). In their experiment, however, they demonstrated a considerably larger effect of irrelevant pictures on memory performance using the pegword mnemonic than when using the rote rehearsal (even though the impact of pictures on the rote rehearsal was significant). Moreover irrelevant pictures did not disrupt the pegword mnemonic more than did DVN (Quinn & McConnell, 1996b). There is thus no conclusive evidence from their experiments to suggest that the effect of pictures is not selective.

1.5.2 Interpretation of findings in terms of the three models

The gateway model

To start with the gateway model, a problem arises immediately when trying to account for the observation that visual short-term memory is insensitive to the effects of irrelevant visual input. In the gateway model, all perceptual input is thought to directly access the WM system (e.g. Atkinson & Shiffrin, 1968; Baddeley, 2000, 2002; Quinn & McConnell, 2006). Any information held in WM would thus be interfered with by new incoming information. The assumption of obligatory access of perceptual input to WM is therefore inconsistent with the findings.

The unitary model

As mentioned in Section 1.4.2, when discussing the results of Cocchini et al. (2002), the unitary model has great difficulty accounting for the remarkably high dual-task performance of participants in certain conditions. In the unitary model, temporary retention and processing are assumed to both require the operation of a single limited capacity attentional system (e.g. Cowan, 1988; Cowan et al., 2007; Engle, 2002). As discussed in Section 1.3.3, Cowan et al. (2007) regard short-term retention as an effortful inhibitory process, which maintains attention on the activated LTM material in the focus of attention, and prevents other activated LTM material from entering the focus. Both short-term image maintenance and mental imagery (i.e. the activation of LTM material and manipulation of images in working memory) would thus require the operation of the focus of attention, controlled by capacity limited executive resources (e.g. Cowan, 1999; 2001; 2005). The unitary model could account for the disruption of visual mental imagery by irrelevant perceptual input by arguing that imagery places a large demand on the limited attentional resources. Viewing irrelevant visual input would also engage attention to some degree, and would involve the activation of LTM. Imagery may be more demanding than short-term retention because of its requirement for the generation process of creating images in working memory from activated long-term memory, and its requirement for the manipulation process. In this view, imagery would be more prone to interference from any type of secondary task that requires attention. At the same time, visual short-term memory might be unaffected by irrelevant visual input because it is simply less attention demanding. It may be relatively easy to keep items to-be-retained in the focus of attention despite the distraction (e.g. Cowan et al., 2007).

This account of the unitary model would run into difficulty, however, when trying to explain the selectivity of the interference effect of irrelevant visual input, as demonstrated by the dissociations in effects of different interference tasks on visual imagery (e.g. Dean et al., 2005; Logie, 1986; Quinn & McConnell, 1996b). These studies showed that the impact of irrelevant visual input could not be due to imagery simply being attention demanding, because other attention demanding secondary tasks did not interfere with imagery (e.g. irrelevant speech). Therefore, the unitary model is not able to account for all data on interference with visual working memory either.

The workspace model

In the workspace model, all perceptual input is assumed to activate LTM directly, prior to this activated material being made available in the WM system for further processing (Logie, 1995; 2003). Working memory in this model is assumed to be functionally distinct from the perceptual system. The workspace model can thus account for the absence of interference of irrelevant visual input with visual short-term retention: in this model, images can be maintained in visual working memory independently of the perceptually driven activation of LTM (Logie, 1995; 2003). The impact of irrelevant visual input on visual imagery can be accounted for by the workspace model as well. The imagery tasks that were found to be disrupted by perceptual input were tasks that specifically depended on the repeated top-down activation of long-term visual representations. These representations are then generated within visual working memory on the basis of these LTM representations. Perceptual input also involves the activation of LTM, because all perceptual input is thought to directly access LTM material. Both these tasks would thus compete for the cognitive resource for activation of LTM (e.g. Logie, 2003). This account would also explain why there is only interference of irrelevant visual input in the encoding and retrieval phases of the pegword mnemonic task, and not in the retention phase. Only the encoding and retrieval phases require the activation of LTM traces, whereas the retention phase involves maintenance of the images in visual working memory.

The account of the workspace model for the disruption of imagery is consistent with the observation that meaningful visual input (for which there is a wide network of associated LTM representations) is more disruptive than abstract visual input (for which there are no clear representations in LTM). Logie (1986), for example, found that the disruptive effect of plain coloured squares on the pegword mnemonic was significant, but smaller than the effect of more complex matrices. Complex matrices could be argued to, like DVN, require activation of LTM, because participants may automatically try to make sense of an otherwise meaningless display by trying to match the display with known objects, patterns or images in LTM (e.g. Logie et al., 2001). The activation of LTM by plain coloured squares would not be so rich. This result thus supports the idea that the visual input has its disruptive effect because it competes with the image generation in imagery tasks for the process of activating LTM representations. Additionally, McConnell and Quinn (2004) demonstrated that when the density or the field size of the DVN display was increased, the disruptive effect increased as well. Also, a static visual noise (SVN) field did not interfere with the pegword mnemonic, and when the rate of change of dot locations was increased, the disruptive effect increased accordingly (McConnell & Quinn, 2000). In sum, the more complex or dynamic the pattern is, the more disruptive its effects. This is again consistent with the idea that the task interferes with image generation because both require the activation of LTM. A complex pattern would activate more LTM representations than a simpler pattern would, and a constantly changing pattern continues to activate LTM in an attempt to recognise objects or shapes, more so than a static pattern would do.

Perhaps even stronger support for the hypothesis that irrelevant visual input disrupts visual imagery because both compete for the activation of LTM comes from a study by Lloyd-

Jones and Vernon (2003). In their series of experiments, participants had to carry out two different visual imagery tasks: (1) a left-right higher decision task, in which they had to decide whether the left or right side of an image was higher, and (2) a taller-wider image inspection task, in which they had to indicate whether a mental image was more tall than it was wide, or the other way around. The mental images on which these tasks were based were learned in an initial training phase, during which participants saw a word accompanied by a line drawing of that object. A number of such stimulus pairs were presented, and participants were told to memorise the picture that the word referred to. In the experimental phase, the names of the drawings to be imaged were presented and participants had to give a vocal response according to whether the left or right side of the image was higher or whether the image was taller than it was wide. The names were presented visually, and a picture distractor of a common object (that had not been memorised) or a non-object was presented simultaneously with the word cue, such that the words were enclosed by the pictures. Reaction times of participants' responses were significantly longer when the distractor pictures were categorically related to the word, compared to when it was unrelated or when it was a non-object picture. The authors argue that this interference effect arises on a semantic level. They argue that a semantic representation of both distractor picture and target word is activated in LTM and that because these representations are categorically similar, the generation of a mental visual image of the target word triggers the same process of image generation for the distractor picture (Lloyd-Jones & Vernon, 2003). This interpretation is consistent with the account of the workspace model for the disruption of imagery by visual perceptual input.

In this context, it is useful to consider a distinction that has been made in the literature, between two types of mental visual images; images generated from stored information in visual LTM and images formed directly from perception as a record of recent visual experience. Visual STM is thought to concern the surface appearance of objects, and visual LTM is thought to involve abstract, structural descriptions of objects in addition (Hitch, Brandimonte, & Walker, 1995; Walker, Hitch, Dewhurst, Whiteley, & Brandimonte, 1997). This distinction appears incompatible with the workspace model, because in this model, images derived from perceptual input would also comprise activated representations from LTM. However, within the workspace model, after LTM representations have been activated, they are considered to be held in a separate, temporary store and do not simply comprise maintaining the long-term representations in an active state as is argued by Cowan (e.g. 2005). Moreover, the number and type of representations that are activated from LTM by visually presented stimuli for an imagery task, depend on the type of stimuli. It was argued above that more meaningful or familiar visual perceptual input is more disruptive of imagery tasks, presumably because there is stronger and more extensive activation of representations in LTM. Likewise, if visually presented to-be-imaged stimuli are rather abstract images, some representations in visual LTM will be activated, but arguably fewer than, for example, the elaborate visual images that are required to be repeatedly activated in the pegword mnemonic. In support of this hypothesis, Avons and Sestieri (2005) have failed to find an effect of irrelevant visual input on an imagery task that depends on abstract images derived from perceptual input. In their ‘cumulative imagery task’, participants were shown a rectangular frame, which formed the border of a matrix of unseen square cells. Half of the cells of the matrix were selected and filled to make a pattern. Cells were displayed one at a time, in a random order, and at a relatively slow rate. Participants were instructed to try to form an impression of what the pattern would look like if all the cells were displayed at once. After all the cells had been displayed, a test pattern was shown very briefly. DVN had no effect on performance on this task, whether it was presented throughout the presentation or retention phase (Avons & Sestieri, 2005). Although the presentation of the cells probably activated some traces in LTM, it is unlikely that substantial repeated activation of complex LTM representations was involved in this task. Within the workspace model, any such representations would by definition, be held in a temporary store that is separate from LTM. To reiterate, the temporary store does not comprise the maintenance of LTM representations in an activated state. The temporary store holds the products (or outputs) of activated LTM representations.

The workspace model thus appears to be able to account for the data on interference in visual working memory, better than do the gateway and unitary models. The account of the workspace model is consistent with some interpretations of the data offered by other researchers. Andrade et al. (2002), for example, report that M. M. Smyth (in personal communication, 1999) suggested that “DVN interferes with retrieval from LTM rather than with storage in WM” (p 771). She suggests this on the basis of the demonstration of disruption of imagery tasks that require generation of images from LTM, such as visualising a route on a previously learned climbing wall (Smyth & Waller, 1998). Also Avons & Sestieri (2005) suggested that one possible interpretation of the selective interference effect of irrelevant visual input is that it “may selectively impair certain processes […] such as the formation of images, or the retrieval of images from LTM, that are not shared by visual

STM" (p 413). However, other authors have offered a different account for the selective impact of irrelevant visual input on visual imagery.

Alternative account of the data

An alternative interpretation that has repeatedly been offered to account for the observation that irrelevant visual input selectively disrupts visual imagery, is the suggestion that there are different anatomical substrates for visual imagery and visual short-term memory. Only the substrate for imagery would then be subject to interference from irrelevant perceptual input. A separation was earlier proposed between a buffer for images generated from LTM and a buffer that maintains recent percepts. This proposal was based on neuropsychological evidence for the separation between visual perception and imagery of visual long-term memory representations (e.g. Hanley, Young, & Pearson, 1991; Riddoch, 1990, see also Section 1.4.1). Andrade et al. (2002) suggested that visual imagery tasks require active processing of visual representations in an 'active store' (which they also refer to as a "workspace" after Logie's (1995) conception of WM). This active store is separate from a 'passive store' used to retain stimuli in visual short-term memory tasks. They furthermore assume that only the active store is susceptible to interference by irrelevant visual material (Andrade et al., 2002). Similarly, Quinn and McConnell (2006) propose different structures for imagery and short-term memory. They suggested that the visual cache of WM (Logie, 1995) is a store for interpreted information from LTM. In addition, they propose a 'passive visual store' as a substrate for conscious visual imagery. (Confusingly, what Quinn and McConnell call the 'passive visual store' is termed the 'active store' by Andrade et al.). Quinn and McConnell assume that their passive visual store is frontloaded by visual perceptual input, and thus susceptible to interference. Andrade et al. (2002) and Quinn and McConnell (2006) thus both assume direct access of visual perceptual input to the system responsible for imagery, but not to the system responsible for short-term memory. This idea again points to the gateway model, in which perceptual input directly accesses the working memory system. The problems with this view have been discussed in Section 1.4.1. Moreover, assuming separate substrates for visual imagery and visual short-term memory would be less parsimonious than the account that the workspace model offers for the data.

On a theoretical level, however, the latter two interpretations are related, in that both propose that there are fundamentally different cognitive processes underlying imagery and short-term retention, even though the proposed processes are different. Andrade et al. and Quinn and McConnell propose that imagery is a conscious, active manipulation process, whereas short-term memory is a non-conscious, passive storage process. The workspace interpretation, on the other hand, differentiates between the image generation process being essential to imagery, and image maintenance to short-term memory. Importantly, this latter interpretation does not assume a separate anatomical substrate for imagery. Perhaps somewhat confusingly, Logie (1995) also speaks about a 'visual buffer' as a medium for visual imagery, but he proposes that this buffer should rather be seen as a *process* than as a separate memory *store*. He proposes that the imagery buffer may be hosted by the central executive, and that this component is responsible for the generation and manipulation of images. The central executive is assumed to be able to extract information from LTM or from the storage components of the WM system (e.g. Baddeley, 1996). The visual cache acts as a temporary back-up store for images (Logie, 1995). However, the central executive is a processing unit and not a storage component. By making the distinction between an image generation process and an image retention process, there is no need to assume more than one storage component to interpret the data. This view is very similar to that of Pearson (e.g. 2001; Pearson et al., 1999; 2001), who proposes a visual buffer that provides an executively controlled workspace for conscious visual imagery (see also Section 1.5). The maintenance of conscious visual images is thus suggested to be the function of the central executive system. He furthermore describes the visual cache as a mechanism for temporary storage of non-conscious visuo-spatial information during imagery tasks if required (Pearson et al., 1999).

The idea that the central executive component is responsible for the generation and manipulation of images is supported by a number of empirical findings which have shown that imagery is highly demanding upon general purpose attentional resources. Concurrent spatial tapping, for example, has been reported to disrupt various imagery tasks, such as mental rotation of abstract shapes (Logie & Salway, 1990) and mental comparison of objects' relative size (Engelkamp, Mohr & Logie, 1995). Salway and Logie (1995) demonstrated that both spatial tapping and random number generation (a task which is generally assumed to engage the central executive (e.g. Baddeley, 1996)) disrupted the Brooks matrix task, a visual imagery task. Random number generation also disrupted a mental creative imagery task (Pearson et al., 1996). Bruyer and Scailquin (1998) investigated disruption of three subprocesses of mental imagery (as defined by Dror & Kosslyn, 1994): image generation, image maintenance and image rotation. They found that both the generation and rotation tasks were disrupted more by random number generation than by the spatial localisation of sounds (hypothesised to require the visuo-spatial sketch pad). None of their interference tasks disrupted image maintenance. Authors argue that their results suggest an important role of the central executive in the generation and rotation of mental images (Bruyer & Scailquin, 1998). Their findings are again highly consistent with the account of the workspace model.

1.5.3 Experiments 1 – 7

The gateway, unitary and workspace model thus all three make different assumptions and predictions about whether irrelevant visual input interferes with visual imagery and visual short-term memory. In the previous section they were contrasted indirectly by reinterpreting the data on interference with visual working memory in terms of the models. It appears that only the workspace model can account for all these data. It can explain the resistance of visual short-term memory to interference, because image maintenance is assumed to take place independently of the perceptually driven activation of LTM. Irrelevant visual input may interfere with visual imagery because both require the activation of LTM. The gateway model cannot account for the lack of disruption of visual short-term retention by irrelevant visual input, because in this model all perceptual input is assumed to have direct access to the WM system. The account of the unitary model, in terms of the differing demand on limited attentional resources of visual imagery and visual short-term memory tasks, does not hold when looking at the studies that have found a dissociation in interference with imagery of different secondary tasks.

The results of these studies therefore provide support for the workspace model. As mentioned before, however, these studies were not intended to explicitly test the different models of the interaction between working memory and long-term memory, and an alternative explanation for the data is still possible. The theoretical interpretations in terms of the three models outlined above have thus still to be fully tested in this context. Moreover, empirical support for the insensitivity of visual short-term retention to interference by irrelevant visual input is growing, but is still relatively thin compared to the evidence for the disruption of visual imagery. The experiments described in this thesis aimed to explicitly address the differential predictions that might arise from the assumptions in each of the three models considered here. As reviewed in this section, investigating interference in visual working memory offers a promising approach to directly compare these different assumptions. In Experiments 1 – 3, dual-task methodology was used to study the interference effects of a picture naming task and two spatial tapping tasks on performance on a pattern memory task. In experiments 4 – 7, the interference effects of irrelevant visual input and spatial tapping on the performance on a visual short-term memory task and a visual imagery task were studied. The same three models were tested in Experiment 8 using a different approach, namely that of cognitive neuropsychology. In this experiment, the three models were contrasted by testing their accounts of the phenomenon of implicit semantic processing of visual material in perceptual neglect patients (see Sections 1.4.1 and 1.4.2, and Chapter 9).

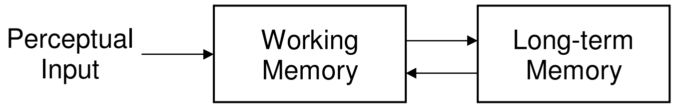
CHAPTER 2

Experiment One

Experiments 1 – 7 aimed to compare the three models of the interaction between working memory and long-term memory directly, by testing their predictions about interference in visual working memory tasks. Section 1.5.1 reviewed the literature on the effects of irrelevant visual input on visual imagery and visual short-term memory. It appeared that the three models each make different predictions and assumptions about these specific effects (see also section 1.5.2). These predictions will be briefly restated here in the context of the specific tasks used in Experiment 1. In this experiment, the effect of a concurrent perception task on performance of a visual short-term memory task was investigated. The perception task was speeded picture naming which had no further memory requirement for the stimuli. This task is assumed to involve the activation of LTM, without any involvement of visual WM (e.g. Alario et al., 2004). The visual short-term retention task involved recall of visual matrix patterns, which has also widely been used as a visual working memory task.

In the gateway model, all perceptual input is assumed to have direct access to the working memory system (e.g. Atkinson & Shiffrin, 1968; Quinn & McConnell, 2006) (see Figure 2.1).

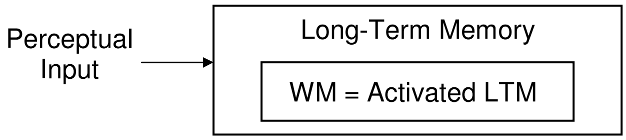
Figure 2.1. Schematic view of the gateway model



Therefore, any visual perceptual input would be predicted to interfere with retention of any other visual information being held in the capacity limited visual short-term store. The gateway model would thus predict a considerable negative impact of the picture naming task on performance of the visual patterns task.

In the unitary model, working memory is seen as comprising the currently activated traces in LTM, and temporary retention of information involves the maintained activation of LTM traces (see Figure 2.2) (e.g. Cowan, 1988; 2005; Cowan et al., 2007; Engle, 2002; Ruchkin et al., 2003).

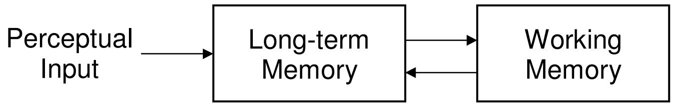
Figure 2.2 Schematic view of the unitary model



Short-term retention is assumed to be an effortful process, requiring the operation of a single capacity limited attentional system (e.g. Cowan, 1988; Cowan et al., 2007; Engle, 2002). The capacity limited executive resources would also be required for directing attention to external sources, and for the activation of LTM material (e.g. Cowan, 1999; Cowan et al., 2007). In this view, a visual short-term memory task and a demanding visual perception task requiring LTM activation would both draw on limited resources for the deployment of attention. The unitary model would therefore also predict substantial disruption of the visual patterns task by a concurrent picture naming task.

In the workspace model, all visual perceptual input is assumed first to activate visual representations in LTM, and these activated representations can subsequently be transferred to visual WM if further processing is required (e.g. Logie, 1995; 2003) (see Figure 2.3).

Figure 2.3. Schematic view of the workspace model



Working memory is seen as a workspace that is functionally separate from the perceptual system (Logie, 1995; 2003). Therefore, the model assumes that information that is already held in WM can be maintained and manipulated independently of perceptual processes. Any visual information held in visuo-spatial WM is thus unaffected by the activation of LTM by perception, as long as there is no requirement to remember this perceptual material. Therefore, the workspace model predicts no disruption of the visual patterns task by concurrent picture naming.

2.1 METHOD

Participants and design

Participants were 36 (22 female; 14 male) native English-speaking students from the University of Edinburgh. Their average age was 22.8 years (*SD* = 4.3). They were recruited via the University employment website, and were paid a small honorarium for taking part. A within-subjects design was used; all participants took part in all experimental conditions. There were two single-task conditions (the pattern memory task and the picture naming task performed independently) and one dual-task condition (both tasks performed simultaneously). The dual-task condition was always given last, and presentation order of the two single-task conditions was counterbalanced across participants.

Materials and stimuli

Visual patterns task

The visual short-term memory task used in this experiment was a version of the visual patterns test (VPT) which has widely been used before (e.g. Della Sala et al., 1999; Logie & Pearson, 1997; Phillips & Christie, 1977). In this task, participants were presented with, and had to recall matrices with some of the cells filled to make a pattern. The version used here was developed by Rudkin, Pearson and Logie (2007). From these previous studies, the task appears to engage short-term visual memory, without too much of a spatial load. Moreover, the simultaneous presentation of pattern elements and the requirement for reproduction of the patterns with pattern elements reconstructed in any order reduce the sequential spatial element in the test. Kemps (2001) demonstrated that patterns with a certain structure (i.e.

containing symmetry, repetition, etc.) can be coded more easily into long-term memory. Therefore, patterns were constructed to be as random and unstructured as possible. This made it less likely that participants were able to use verbal memory or long-term memory strategies for retention

The patterns were presented on a square (24 x 24 cm) button box (Rudkin et al., 2007) in front of the participant. The box was 10 cm high. An array of 25 (5 by 5) square buttons (of 2 x 2 cm each) was displayed on the top surface. This ‘presentation box’ was connected to a second box of the same size. This second ‘control box’ (out of sight of participants) contained the same array of buttons, and had a few extra options to adjust settings for the presentation of patterns. The experimenter constructed patterns on the control box, which could then be transferred (all buttons in a pattern simultaneously) to the presentation box where the patterns were displayed by the corresponding buttons lighting up for 5 seconds. After a blank delay period of 15 seconds, participants had to try and reproduce the original patterns by pressing the buttons, which were lit when pressed. These buttons remained lit until the experimenter switched them off. Once a button was pressed, it could not be retracted and all participants were warned of this in advance. The recalled patterns immediately became visible on the control box, from which the experimenter could record the performance of participants.

A set of 20 random and unstructured patterns was created, each with 8 of the 25 squares ‘filled’ (see Appendix A). Ten of these 20 patterns were presented in the single-task condition, and the other 10 in the dual-task condition. The first pattern in each condition functioned as a practice trial, leaving 9 patterns in each condition for the experimental trials. Three different versions of the pattern list were made by changing the order of the 20 patterns within the list. Individual patterns were thus counterbalanced across the two conditions. Participants were randomly assigned to one of the three versions.

Picture naming task

The second task was a speeded picture naming task. Stimuli were pictures of common objects and animals, taken from the standard picture set of Snodgrass and Vanderwart (1980). Pictures were blurred and presented in grey scale (to avoid ceiling effects). A few examples of these pictures are given in Figure 2.4. A full list of names of all pictures used is included in Appendix B.

Figure 2.4. Some examples of stimuli used in the Picture Naming Task

Airplane Bear

Bicycle Fly

Pictures were presented in the middle of a computer monitor on a white background using E-Prime software, and ranged in size from 5 to 10 cm in width and height. Viewing distance of the monitor was approximately 50 cm. Presentation time of pictures was 250ms with an inter-stimulus interval of 1200ms. Each trial consisted of a series of 9 pictures, so total duration of a trial was 14250ms. Reaction time of naming the pictures was measured with a voice key, and recorded in E-prime. The experimenter recorded whether or not each picture was named correctly. Presentation of the series of 9 pictures in each trial was initiated by the participant pressing the space bar.

Three lists of 180 pictures were created, with 9 pictures in each of the 10 single-task trials, and 9 pictures in the 10 dual-task trials. Presentation order of individual pictures was completely different in each list, with individual pictures counterbalanced across conditions. To avoid a priming effect in the picture naming, consecutive pictures in a trial were never related semantically in any way, and their names were all phonologically distinct. Participants were randomly assigned to one of the three lists.

Pilot studies were carried out before the experiment, to adjust parameters of the different variables of both tasks (such as presentation time, picture format, etc.), in order to achieve performance levels that were above floor and below ceiling. A floor effect in one of the tasks could produce no significant effect on the second task purely for this reason. Similarly, a ceiling effect in one task could obscure any effects of a secondary task. Furthermore, it was attempted to match performance levels on both tasks as closely as possible, as this could rule out any explanations of interference effects on the basis of task difficulty.

Procedure

Participants were tested individually in a quiet test room, with black out blinds and a minimum of irrelevant visual stimuli in the room that may have interfered with the tasks. Participants were seated at a large desk, on which was the button box for the visual patterns task. Behind the button box was the computer monitor for the picture naming task. In the retention interval of the single-task condition of the visual patterns task, participants were instructed to look at a white screen on the computer monitor as soon as the pattern disappeared. The experimenter recorded time with a stopwatch and gave a recall signal after 15s

For the picture naming task, participants were instructed to name the pictures as rapidly and as accurately as possible, trying to only give one short response. It was explained that the computer did not record *what* they said, but *when* they said it, but that the experimenter would record the name they generated for each picture. For the voice key to pick up their voice, participants had to speak loud and clear, and try to avoid saying "ehm" or make other interfering sounds. In case the voice key picked up sounds other than the naming response first, a note was made by the experimenter, in order to remove this reaction time before analysis.

In the dual-task condition, during the retention interval for the visual pattern, participants had to press the space bar to initiate the presentation of the pictures for the naming task as soon as the pattern disappeared. After naming the 9 pictures, they had to return to the button box and reproduce the pattern. The experimenter sat next to the participant throughout the test session, to check whether participants complied with these instructions (and to remind the participant about instructions if necessary), and to score performance on both tasks.

2.2 RESULTS

Visual patterns task

The measure of recall performance on the visual patterns task was the average proportion of correctly reproduced buttons in each pattern. The maximum absolute score for each pattern was 8, and if more than 8 buttons were pressed by the participant, the number of extra buttons was subtracted from the score of that trial. Mean data are given in Table 2.1.

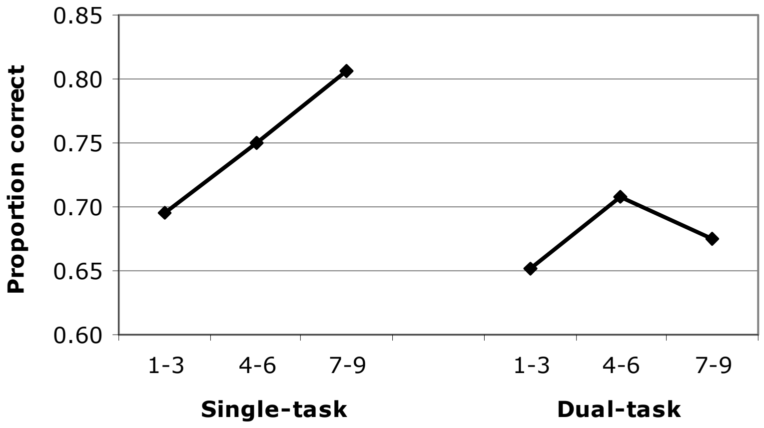
Table 2.1. Mean performance on the Visual Patterns Task (max = 8) and the Picture Naming Task (max = 9) in the single- and dual-task condition

	Single-task		**Dual-task**	
	M	*SD*	*M*	*SD*
Visual patterns	.75	.11	.68	.11
Picture naming	.72	.72	.67	.91

Performance levels on the visual patterns task were well below ceiling and above floor. There was a drop in performance of 9.4% between the single and the dual-task condition. score. This difference was significant, $F(1,35) = 13.25$, $p = .001$.

The possibility that a fatigue effect contributed to the drop in performance in the dual-task condition (which was always given last) was investigated by dividing all trials into groups of three. Performance levels were compared between these groups. Mean data are shown in Figure 2.5.

Figure 2.5. Mean performance levels on the visual patterns task, separate for groups of 3 trials each



Comparison of the three groups of trials in the single-task condition shows that performance is going up rather than down, suggesting a learning effect rather than a fatigue effect. This increase is significant, $F(2,34) = 13.12$, $p < .001$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed a significant difference between the first and second group of trials, $p = .013$, and between the second and third, $p = .012$.

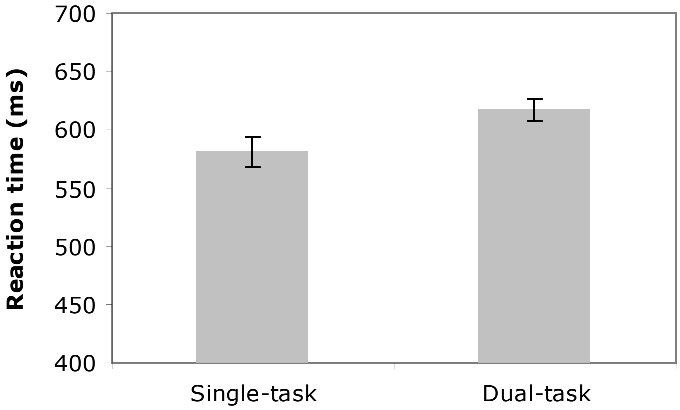
For the dual-task condition, the equivalent scores across trial groups did not differ significantly $F(2,34) = 1.05$, $p = .35$. There was thus some evidence for a learning effect in the single-task condition, but no effect of fatigue effect in either condition. Therefore it is unlikely that the lower performance under dual-task conditions could be attributed to a build up of fatigue across the experiment.

Picture naming task

One measure for the performance on the picture naming task was the average proportion of correctly named pictures in each trial. The maximum absolute score in each trial was 9. Participants' responses were compared to a list of names of different frequencies from the Snodgrass and Vanderwart (1980) norms. Credit was given for any response that also occurred in this list, and for common British-English names for the objects when these differed from the Snodgrass and Vanderwart American-English names (e.g. trousers for pants, or pram for baby carriage, see Appendix B). Mean data are given in Table 2.1. The difference in performance between the single and dual-task conditions in terms of absolute scores was 6.8% of the single-task condition score, which was significant, *F*(1,35) = 10.27, p = .003.

Another measure for the performance on the picture naming task was the reaction time of naming the pictures. Naming time was taken as the time between the onset of the picture on the monitor and onset of the voice of the participant. Recorded reaction times below 450ms were not included in the analysis, because these are well below the range of normal vocal reaction times, and more likely to reflect background noise picked up by the voice key. Reaction times associated with irrelevant vocal responses that had been noted by the experimenter were also excluded. The reaction time data of three participants were not available due to a failure of the computer to record the data. Average reaction times in ms are shown in Figure 2.6. Only reaction times of correctly named pictures were included in this analysis. The difference in reaction time between the two conditions (36ms) was significant, *F*(1,35) = 13.29, *p* = .001, indicating that participants were somewhat slower to name the pictures in the dual-task condition than in the single-task condition.

Figure 2.6. Reaction time of picture naming in both conditions



Effect of presentation order

Between-subjects ANOVAs were carried out to investigate whether there were any effects on performance of presentation order of the two single-task conditions. There were no significant effects of presentation order on performance on either task, with all F < 2.4.

2.3 DISCUSSION

Performance levels of both tasks were significantly lower in the dual-task condition than in the single-task condition. The disruption of a visual short-term retention task by a visual perception task was not predicted by the workspace model, but was predicted by both the gateway and unitary models. These results are inconsistent with studies that have shown no effect on visual short-term retention tasks of visual interference tasks (e.g. Andrade et al., 2002; Avons & Sestieri, 2005; Zimmer & Speiser, 2002).

The workspace model predicted no interference effect in this experiment because in this model, the patterns would be stored in the visual cache component of working memory, where they can be maintained independently of the activation of representations in the long-term knowledge base by the pictures (Logie, 1995; 2003). The present results could be interpreted as the competition for processing in visual working memory (as predicted by the gateway model), or for the requirement of limited attentional resources (as predicted by the unitary model). However, an alternative interpretation, consistent with the workspace model, is that the significant impact of the picture naming task reflects the increase in general processing load associated with the dual-task requirements. The tasks individually were already demanding (performance was well below ceiling), and the increased load on attentional and executive components for coordination in the dual-task condition might have led to the drop in performance in both tasks (e.g. Duff & Logie, 2001; Logie, Zucco & Baddeley, 1990). Another possible explanation for the interference effect between both tasks is that LTM somehow contributed to the retention of patterns in the visual patterns task. Even though all care has been taken to avoid patterns with an obvious structure, it may still have been possible that participants detected continuity, symmetry or other structure in the patterns. Such structure would have helped the encoding of patterns into LTM. Some support for this hypothesis comes from the informal verbal feedback of participants after the experiment. Some participants reported that they could see shapes or images in the patterns, which helped them to remember the patterns. The encoding and retrieval of patterns in LTM might then have been disrupted by the activation of LTM by the pictures, causing a small drop in performance in the dual-task condition. Additionally, it is possible that visual WM was involved in the picture naming task, even though no particular demand for retention or manipulation was required in this task. Visual representations of the pictures may have been transferred automatically from LTM to WM systems. A participant making an overt response to a consciously perceived object image could be argued to temporarily hold the image in

WM. The temporary retention of representations of the pictures in visual WM might then have disrupted retention of the patterns in the same storage component.

These latter possible interpretations of the workspace model would gain stronger support from the demonstration of a significantly larger disruption of the visual patterns task by a secondary task that does not involve perception, but involves visual WM, and for which there is good reason to be confident that overall demand is equated to that of the picture naming task. The workspace model would then predict a larger interference effect than in the present experiment, because the secondary visual WM task would compete with the visual patterns task for resources in the visual cache – the temporary storage component. The gateway model would predict an equally large disruption of performance on the visual patterns task by both, a secondary task involving perception and a secondary task involving visual WM, because in the gateway view, both types of tasks would involve processing in the working memory system. The predictions of the unitary model would depend on the exact demands (on limited attentional resources) of both tasks. Experiment 2 was designed in an attempt to explore whether a different secondary task thought to require the visual cache within the workspace model would generate similar or greater interference with visual immediate memory than does picture naming.

CHAPTER 3

Experiment Two

In Experiment 2 the predictions of the three types of models were explored further by combining the visual patterns task of Experiment 1 with a tapping task. Tapping tasks have been used frequently in experimental interference paradigms, and have repeatedly been demonstrated to disrupt visual working memory processes (e.g. Andrade et al., 2002; Della Sala et al., 1999; Engelkamp et al., 1995; Salway & Logie, 1995). Andrade et al. (2002), for example, found a significant effect of a simple tapping task (involving fast unseen tapping between only two keys) on a visual matrix patterns task. Their visual patterns task was very similar to that used in the present experiments; participants were presented with 5 x 5 matrices with 9 cells filled, and had to reproduce these patterns after a retention interval. Also Della Sala et al. (1999) demonstrated a significant impact of tapping on a similar visual patterns task, even though another visual interference task (viewing abstract paintings) had a larger impact than did tapping. Their tapping task was also a simple unseen tapping task, involving only 4 keys.

It is true that tapping tasks have usually been employed specifically to disrupt spatial rather than visual processing within the working memory system. Tapping tasks have indeed repeatedly been found to affect the Corsi blocks task (or similar spatial memory tasks based on the Corsi blocks task) (e.g. Kemps, 2001; Logie & Marchetti, 1991; Smyth, 1996; Smyth & Scholey, 1994; Vandierendonck, Kemps, Fastame, & Szmalec, 2004; Zimmer, Speiser, & Seidler, 2003), as well as various other tasks that involve spatial, rather than visual processing, such as the manikin task (e.g. Farmer, Berman, & Fletcher, 1986) and the Brooks spatial task (e.g. Quinn & Ralston, 1986). The effect of tapping has been interpreted as the disruption of the inner scribe component, which has been described as being responsible for the planning and execution of movement, as well as for rehearsal of material in the visual cache for which spatial sequential information is important (Logie, 1995). The mechanism of the interference effect is thought to be through shifts in spatial attention or engaging the processes involved during the planning and production of physical movement or oculomotor control (e.g. Pearson, 2007). There is evidence, for example, for a considerable overlap between the frontal, parietal, and posterior extrastriate brain regions that participate in spatial working memory and in spatial selective attention (e.g. Awh, Anllo-Vento, & Hillyard, 2000; Awh & Jonides, 2001; Awh, Sgarlata, & Kliestik, 2005). Consistent with the above suggestion of the mechanism of interference, spatial tasks have also been disrupted by arm movements (e.g. Lawrence, Myerson, Oonk, & Abrams, 2001; Pearson & Sahraie, 2003; Quinn & Ralston, 1986; Smyth & Scholey, 1994), eye movements (e.g. Lawrence, Myerson, & Abrams, 2004; Lawrence et al., 2001; Pearson & Sahraie, 2003; Postle, Idzikowski, Della Sala, Logie, & Baddeley, 2006), or simply shifts of attention (e.g. Lawrence et al., 2004; Pearson & Sahraie, 2003; Smyth, 1996; Smyth & Scholey, 1994).

In the present experiment, the specific tapping task that was used was assumed to pose an additional load on *visual* working memory for three reasons. Firstly, the tapping pattern was a complex figure-of-eight pattern on a three-by-three tapping board. Most tapping tasks described in the literature are simple tapping tasks, using only two or four keys. Secondly, the tapping was unseen, so participants received no visual feedback about the tapping, and had to form a mental image of the tapping board and pattern, to keep track of the tapping sequence. Thirdly, a foot tapping task was chosen rather than a finger tapping task, to enlarge the spatial extent of the movements involved, and make the task more demanding. This foot tapping task could also readily be set up to avoid visual perceptual input. In the workspace model, keeping track of a tapping sequence and maintaining a visual tapping pattern would pose an additional load on visuo-spatial working memory on top of maintaining the patterns. The workspace model would therefore predict a much larger disruption of the visual patterns task by unseen tapping than by the picture naming task of Experiment 1.

3.1 METHOD

Participants and design

Participants were 36 (18 female; 18 male) students from the University of Edinburgh. Their average age was 21.5 years (*SD* = 2.7). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in Experiment 1. Like in Experiment 1, a within-subjects design was used; all participants took part in the two single-task conditions (visual patterns task and tapping task on their own) and in the dual-task condition (both tasks simultaneously). The dual-task condition was always given third, whereas the order of the single-task conditions was counterbalanced across participants.

Materials and stimuli

Stimuli and administration of the visual patterns task were identical to those in Experiment 1, with the same three pattern lists allocated to different conditions, counterbalanced across participants. The foot tapping device was a wooden apparatus, measuring about 50cm long by 40cm deep, consisting of three platforms of increasing heights - similar to that of three steps. Each of these steps was approximately 5 cm high and held a row of three foot switches (each of about 5 x 10 cm). Foot switches were thus organised in a three-by-three array. The apparatus was connected to a computer with software that recorded when each of the buttons was pressed. It was placed underneath the desk and participants could not see the device or their feet.

Procedure

The general procedure was similar to that of Experiment 1. Participants were tested individually in a quiet test room, without windows and a minimum of irrelevant visual stimuli. They were seated at a large desk against a white wall, with the presentation box of the visual patterns task in front of them, and the foot tapping board underneath the desk in front of them. The experimenter sat next to the participant, giving instructions, scoring the different measures of performance and presenting the patterns on the control box of the visual patterns task.

Depending on the group to which they were assigned, participants received either the single-task condition of the visual patterns task or of the tapping task first. They received a practice trial before starting each of the three conditions. In the tapping task, participants were instructed to tap as accurately as possible, with their 'preferred foot'. The specific pattern they were instructed to follow was that of a figure-of-eight, starting at the left most foot switch on the top row, at a rate of 2 taps per second. In the practice trial the speed of tapping was indicated by a computer, which generated two beeps per second, while participants synchronised their tapping with the beeps. Throughout the rest of the experiment participants had to attempt and maintain this speed as accurately as possible but without the beeps. The single-task condition of the tapping task consisted of 9 trials in which participants tapped for 15s each. In the dual-task condition, participants carried out the tapping task in the retention interval of the visual patterns task. They were first presented with a pattern, to which they attended for 5s. After the pattern disappeared they were required to start tapping until the experimenter indicated the end of the 15s retention interval. They then had to return to the button box and attempt to reproduce the pattern. This sequence of events was repeated 9 times. Participants were instructed to keep looking at a small black cross up on the wall in front of them, both during tapping and in the unfilled retention interval in the single-task condition of the visual patterns task.

3.2 RESULTS

Visual patterns task

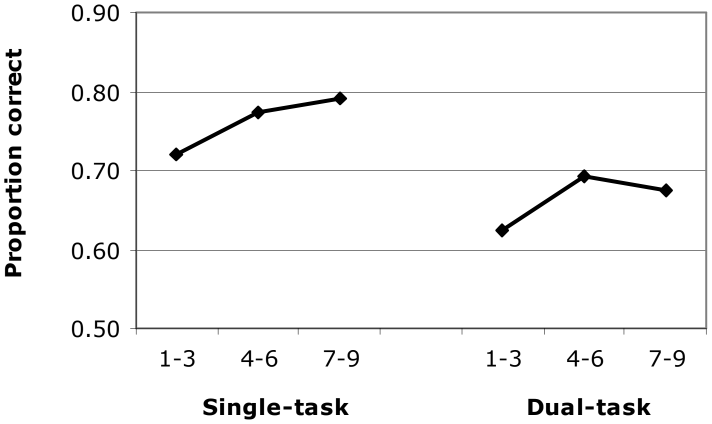
Scoring methods were similar to those in Experiment 1. Performance on the visual patterns task was taken as the mean proportion of buttons correctly reproduced in each pattern. Mean data are given in Table 3.1. The difference between the two conditions on the visual patterns task was significant, $F(1,35) = 37.80$, $p < .001$.

Table 3.1. Mean performance on the visual patterns task in single- and dual-task condition

	Mean	**SD**
Single-task	.76	.10
Dual-task	.66	.12

The possible presence of fatigue effects (possibly contributing to the drop in performance in the dual-task condition) was tested by dividing the 9 trials of each condition into three groups of three trials each, and comparing the mean performances between these groups. Mean data are shown in Figure 3.1.

Figure 3.1. Mean performance levels on the visual patterns task, separate for groups of 3 trials each



Like in Experiment 1, performance is going up in the second and third group of trials in the single-task condition, suggesting a learning effect rather than a fatigue effect. This increase in performance was significant, *F*(2,34) = 4.04, *p* = .02. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed that there was a significant difference between the first two groups of trials, *p* = .041, and between the first and third group, *p* = .022. In the dual-task condition performance went up in the second group of trials compared to the first, but down again in the third group of trials. This difference was significant overall, *F*(2,34) = 3.49, *p* = .036. Post-hoc pair-wise comparisons revealed that there was a significant difference between the first and second group, *p* = .033, but no difference between the first and third, or second and third. Overall, there was thus some evidence for a learning effect, but not for a fatigue effect that could account for the drop under dual task conditions.

Tapping task

Performance on the tapping task was analysed on the basis of two measures: the accuracy of maintaining the correct overall tapping speed, and the constancy of tapping speed. The buttons of the foot tapping device had to be pressed very firmly for the computer to be able to read the signal. Therefore, many taps were not recorded and accuracy of maintaining the tapping pattern could not be assessed. However, the number of missing taps was not different between single-task and dual-task conditions. A measure for the overall tapping speed was the mean of between-tap intervals across trials, ignoring intervals that were greater than 0.90s, indicating missing taps. Constancy of speed of tapping was measured by taking the standard deviation of between-tap intervals across trials. Mean data are shown in Table 3.2.

Table 3.2. Mean speed (in s) and mean constancy of speed (in s) of tapping, in the single- and dual-task condition

	Speed		**Constancy of speed**	
	M	*SD*	*M*	*SD*
Single-task	0.54	0.06	0.07	0.02
Dual-task	0.49	0.08	0.06	0.02

The difference in the mean tapping speed between conditions was significant, $F(1,35) = 30.19$, $p < .001$; participants tapped faster in the dual-task condition than in the single-task condition. The difference in the constancy of speed between conditions was not significant, $F(1,35) = 2.77$, $p = .11$.

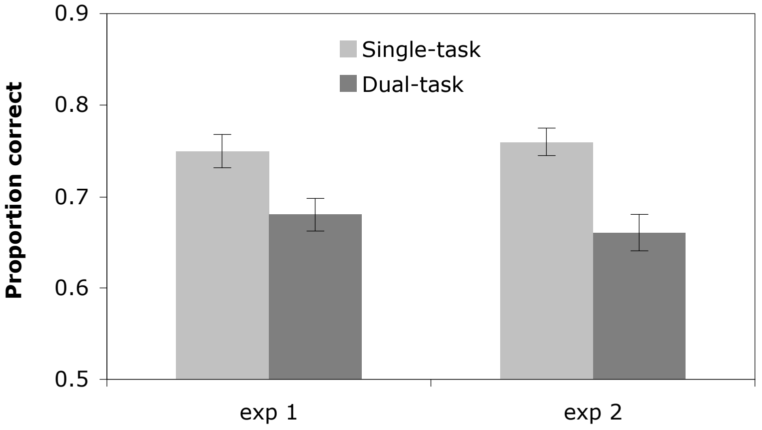
Effect of presentation order

Between-subjects ANOVAs were carried out to investigate whether there were any effects on performance of presentation order of the two single-task conditions. None of the effects were significant, with all $F < 1$.

Comparison of Experiment 1 and 2

Given that the designs of Experiments 1 and 2 were identical, an overall ANOVA was conducted, treating Experiment (type of secondary task) as a between-subjects variable. This allowed comparison of the interference effects on performance on the visual patterns task of the picture naming task of Experiment 1 and the tapping task of Experiment 2. Mean performance on the visual patterns task in the two experiments is shown in Figure 3.2.

Figure 3.2. Mean performance on the visual patterns task in Experiment 1 and 2



There was a main effect of condition, *F*(1,35) = 45.84, *p* < .001, but no main effect of interference task, *F*(1,35) = .01, *p* = .93, or an interaction between condition and interference task, *F*(1,35) = 1.57, *p* = .22.

3.3 DISCUSSION

The simultaneous figure-of-eight tapping task caused a significant drop in performance on the visual patterns task. Contrary to the prediction of the workspace model, there was no interaction between condition of the visual patterns task and type of interference task (picture naming of Experiment 1, and tapping in the present experiment); the impact of tapping was as strong as that of picture naming. Performance on the tapping task itself did not differ much between conditions: participants tapped a little faster, but there was no decrease in the constancy of speed in the dual-task condition.

The impact of both a visual perceptual task and a visual working memory task on the pattern memory task could be explained by the gateway model, because the pictures, tapping pattern and visual matrix patterns would all compete for processing in one limited storage component (e.g. Atkinson & Shiffrin, 1968). The unitary model could account for the results of both Experiment 1 and 2, in terms of the demand on attentional resources of both secondary tasks. It would have to be assumed that the picture naming task and the tapping task are equally attention-demanding. However, the unitary account is post-hoc because it makes no clear predictions about which tasks would be the most and which task the least demanding. The workspace model did make clear predictions, but these were not confirmed.

A possible alternative explanation for the failure to find a significantly larger effect of tapping than of picture naming, is that the tapping task is still more spatial than visual in nature, even though it was argued above that this specific tapping task poses a load on visual processing. In the workspace model, both the planning and execution of movement (tapping) and the rehearsal of the contents of the visual cache (maintaining the matrix patterns) would require the operation of the inner scribe component. However, the inner scribe might be more involved in the rehearsal of material for which sequential information is important, such as the Corsi blocks task. Moreover, participants are unlikely to consciously rehearse the patterns during the retention interval. Especially in Experiment 1, participants were engaged in a secondary task requiring conscious processing and attention during the retention interval of the visual patterns task. This should prevent conscious and attention demanding rehearsal of the patterns, and yet they still remembered on average 68% of the patterns, as compared to 75% in the single-task condition. This suggests that storage in the visual cache does not necessarily require the conscious rehearsal by means of the inner scribe, contrary to the original assumption linking these two components (Logie, 1995). If thus the visual patterns task mainly relies on storage in the visual cache, and the tapping task relies on the inner scribe, no large interference effect would be expected between the two tasks. That the visual and spatial components of WM can indeed function independently has repeatedly been demonstrated (e.g. Darling et al., 2006; Della Sala et al., 1999; Logie & Pearson, 1997).

In Experiment 3, the visual patterns task was combined with a secondary task that is more likely to involve visual and not spatial processing, in a second attempt to demonstrate a dissociation in interference effects on the visual patterns task between the picture naming task and a visual WM task.

CHAPTER 4

Experiment Three

In Experiment 3 the same visual patterns task of Experiment 1 and 2 was combined with a letter imaging task, in which participants were required to form mental images of auditorily presented letters of the alphabet, and subsequently mentally to inspect these images to answer questions about them. Maintenance and inspection of the visual images is assumed to rely on the visuo-spatial sketch pad of working memory. The workspace model would predict a substantial disruption of maintaining the visual patterns by the letter imaging task, because both tasks require the visual cache component. Moreover, the workspace model would predict that the disruption by this secondary task will be much more substantial than that of the picture naming task in Experiment 1. In the workspace view, the retention of visual material in WM is independent of the activation of LTM by irrelevant visual input, whereas the images of the patterns would be disrupted by other images being held in visual WM.

4.1 METHOD

Participants and design

Participants were 36 (23 female; 13 male) native English speaking students from the University of Edinburgh. Their average age was 20.5 years (*SD* = 1.8). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in any of the previous experiments. The same within-subjects design as in Experiments 1 and 2 was employed; all participants took part in the two single-task conditions (both tasks on their own) and in the dual-task condition (both tasks simultaneously). The dual-task condition was always given third, and the order of the single-task conditions was counterbalanced across participants.

Materials and stimuli

The visual patterns task was administered as in Experiments 1 and 2, with the same three pattern lists counterbalanced across participants. Procedure and stimuli for the letter imaging task were based on similar tasks reported in the literature (e.g. Coltheart, Hull, & Slater, 1975; Kosslyn et al., 1993; Weber & Castleman, 1970). Like the visual patterns task, the letter imaging task consisted of 9 experimental trials and 1 practice trial in both the single- and dual-task condition. Each experimental trial either contained the letters A-M in random order or the letters N-Z in random order, and these letter sets alternated each trial. This way, no letter appeared twice in one trial, no letter appeared in two consecutive trials, and each letter was used the same number of times in each condition of the experiment. Digital sound files were created to present the letters auditorily, by reading out the letters at a rate of 1 letter per second. These sound files were played back on a desktop computer using Microsoft Power Point. Each trial consisted of 13 letters, resulting in a total duration of about 15 seconds for each trial (including a 1s interval before presenting the first letter, and a 1s interval for response to the last letter). Participants started each new trial by pressing the space bar.

The participants’ task in each trial was to listen to the letters, and create a mental visual image of the capital forms of each letter as they heard them. They were instructed to always imagine the standard upper-case forms of letters, as they are displayed on a computer keyboard. They then had to make a judgment about certain visual features of the letters, by giving a verbal ‘yes/no’ response to each letter. The criteria according to which they had to make these judgments were different in each trial. They concerned horizontal and vertical symmetry, the presence of curves, the presence of straight lines, enclosed spatial areas, similar upper- and lower case forms, the presence of any parallel lines, complexity (i.e. whether the letter is constructed of one single line or not) and the presence of right angles. A full list of all combinations of letters and criteria with the correct answers is included in Appendix C. The 9 criteria were given in a different order in the dual-task condition than in the single-task condition, and each criterion was matched with a different set of letters in the two conditions. Participants thus never received exactly the same combination of letters and criterion more than once throughout the entire experiment. Furthermore, three different versions of combinations of letters and criteria were created, and these three lists were counterbalanced across participants. In the practice trial, the numbers 0-9 were used instead of letters, to avoid any learning effects for specific combinations of letters and criteria.

Procedure

The general procedure was similar to that of Experiments 1 and 2. Participants were tested individually in a quiet test room, without windows and a minimum of irrelevant visual stimuli. They were seated at a large desk with the presentation box of the visual patterns task in front of them, and behind that a computer monitor displaying a white screen. Participants were instructed to always look at the white screen throughout all conditions of the experiment. The experimenter sat next to the participant during the entire experimental session, checking compliance of participants with the task-specific instructions, and recording performance on both tasks by taking notes on paper.

Depending on the group to which they were assigned, participants received either the single-task condition of the patterns task or of the letter imaging task first. They received a practice trial before starting each of the three conditions. Procedure and instructions for the visual patterns task were identical to those in Experiments 1 and 2. In the single-task condition of the letter imaging task, participants were given detailed explanations of each of the criteria, and were shown examples of letters from the Greek alphabet that matched the different criteria, before starting each trial. In the dual-task condition, participants performed the letter imaging task within the 15s retention interval of the visual patterns task. In each trial, they were first instructed which criterion to use for that trial, before being presented with the pattern. As soon as the pattern had disappeared (after 5s), participants had to press the space bar to start presentation of the letters. After having responded to all letters, they then had to attempt to reproduce the pattern.

4.2 RESULTS

Visual patterns task

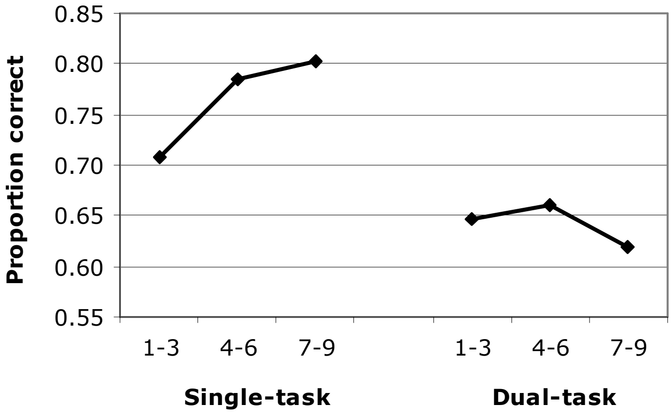
Scoring methods were similar to those in Experiments 1 and 2. Performance on the visual patterns task was taken as the mean proportion of buttons correctly reproduced in each pattern. Mean data are given in Table 4.1. The difference between the two conditions on the visual patterns task was significant, $F(1,35) = 49.77$, $p < .001$.

Table 4.1. Mean performance levels on the visual patterns task and letter imaging task in single- and dual-task condition

	Single-task		**Dual-task**	
	M	*SD*	*M*	*SD*
Visual patterns task	.77	.10	.64	.11
Letter imaging task	.79	.07	.81	.09

The possible presence of fatigue effects in the visual patterns task (possibly contributing to the drop in performance in the dual-task condition) was tested by dividing the 9 trials in each condition into three groups of three trials each, and comparing the mean performances between these groups. Mean data are shown in Figure 4.1.

Figure 4.1. Mean performance levels on the visual patterns task, separate for groups of 3 trials each



In the single-task condition, performance levels increased over the three groups of trials. This increase was significant, $F(2,34) = 9.89$, $p < .001$, suggesting a learning effect over trials. Post-hoc pair-wise comparisons of the three trial groups using a Newman-Keuls test revealed a difference between the first and second group, p < .005, and between the first and third group of trials, p < .001. In the dual-task condition performance levels were not significantly different, $F(2,34) = 1.02$, $p = .37$. There was thus no evidence for a fatigue effect in the visual patterns task within conditions, rendering it unlikely that there was an overall fatigue effect contributing to the lower performance in dual-task condition.

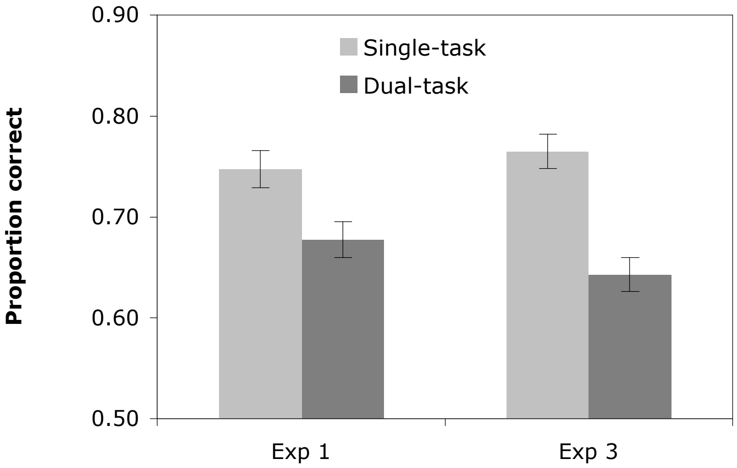
Letter imaging task

A measure of performance on the letter imaging task was the mean proportion of correctly named pictures in each trial. Mean data are given in Table 4.1. The difference between the two conditions was not significant, *F*(1,35) = 3.41, *p* = .073; participants performed as well in the dual-task condition as in the single-task condition.

Comparison of Experiment 1 and 3

The designs of Experiments 1 and 3 were identical, and used different participants. Therefore and overall analysis was conducted to contrast between groups, the interference effects on performance on the visual patterns task of the secondary tasks in Experiment 1 (picture naming), and in Experiment 3 (letter imaging). Mean performance levels of the two experiments are shown in Figure 4.2.

Figure 4.2. Mean performance levels on the visual patterns task in Experiments 1 and 3



A 2 x 2 ANOVA with condition (single-task versus dual-task) as within-subjects variable and interference task (picture naming versus letter imaging) as between-subjects variable revealed a significant main effect of condition, $F(1,35) = 55.21$, $p < .001$, no main effect of experiment, $F(1,35) = .16$, $p = .69$ and a significant interaction , $F(1,35) = 4.11$, $p = .047$, such that letter imaging generated significantly more interference than did picture naming.

4.3 DISCUSSION

The letter imaging task interfered significantly with performance on the visual patterns task. Moreover, letter imaging in the current experiment disrupted visual pattern memory performance significantly more than did picture naming in Experiment 1. This interaction between secondary task type and experimental condition was predicted by the workspace model. These data are difficult to explain with a model in which WM is seen as a gateway for perceptual information on its way to the long-term knowledge base. In this model, simply viewing pictures would result in the automatic representation of this visual information in WM, where the retention of any other information would be disrupted. In this view, the disruption of a visual short-term memory task by picture naming would not be different from the disruption by another task requiring visual WM, such as the letter imaging task. Indeed, the gateway model might well predict less interference from letter imaging given that no visual perceptual input was involved. The gateway model can thus not give an account for the differential interference effects of picture naming and letter imaging.

The unitary model would also predict some interference from letter imaging on the visual patterns task, simply because both are attention demanding tasks. However, it is difficult to decide a-priori the relative attentional demands of letter imaging and picture naming, and so no clear predictions could be made about relative levels of interference. This model could account for the data post-hoc by assuming that the letter imaging task is more demanding of the capacity limited attentional resources (e.g. Cowan, 1995; Cowan et al., 2007) than is picture naming, and therefore was more disruptive to retaining the patterns. However, the picture naming and letter imaging tasks were very similar in many respects: they both required speeded verbal responses of the participant and both involved the activation of long-term memory (of the names of objects shown in the pictures and of the letter shapes indicated by the heard letter names) cued by external stimuli . It is therefore not clear why the letter imaging task should have been so much more attention demanding than the picture naming task.

A more convincing explanation of the interaction between secondary tasks of Experiment 1 and 3, and the two experimental conditions, is offered by the workspace model. In terms of this model, the picture naming task and letter imaging task differ fundamentally in the requirement for cognitive processing. The picture naming task involves the activation of LTM, but does not require storage in visual WM. In contrast, the letter imaging task requires the activation of LTM, but *also* the further processing in visual WM, for inspection and manipulation of the visual representations of the letters. It is this further processing of the letters which is assumed to interfere with the short-term retention of patterns, in the same component of the WM system. The picture naming would be predicted to disrupt maintenance of the visual patterns less, because WM retention in the workspace model is independent of perceptual processes (e.g. Logie, 1995; 2003).

One of the key differences between the workspace model on the one hand, and the gateway and unitary model on the other, is the former model's assumption of the independence of perception processes and WM processes. Specifically, it distinguishes between maintenance of visual information in visual WM, and the processes of LTM activation to achieve, for example object recognition and image generation. Experiments 4 – 7, were designed to explore further the differences between the three models, by contrasting interference effects on tasks that require these image retention and image generation processes.

CHAPTER 5

Experiment Four

Experiment 4 investigated the interference effects of irrelevant visual input on the processes of *generation* of visual images based on long-term memory representations, and of immediate memory for visual information (short-term image *retention*). The letter imaging task was taken as the image generation task. This task was used in Experiment 3 because its requirement for visual WM processing was assumed to be greater than for picture naming, and it was employed there primarily as an interference task. Although an interference effect of this task with the visual patterns task was found, the load on visual WM for storage from letter imaging is still quite small because the letters are presented very fast and the judgments about the letters are made quickly. In the present experiment, the letter image generation task is used as a primary processing task that is assumed to require the activation of visual representations of letters from LTM, and the generation of these images. The image retention task involved remembering strings of four visually presented letters in the sequential order of presentation and whether they were presented in upper or lower case. This specific task was chosen because it uses the same type of experimental stimuli as the generation task, and therefore allows for a more direct comparison. Moreover, this task has been used before in the literature, and has been shown to reliably draw on visual processing for remembering visually presented letter sequences (e.g. Logie, Della Sala, Wynn, & Baddeley, 2000). Each of these tasks was combined with irrelevant visual input in the form of dynamic visual noise (DVN), because this has been used extensively in the investigation of visual interference effects in working memory.

In the workspace model (Logie, 1995; 2003; Logie & van der Meulen, in press), retaining visual information on a temporary basis is seen as functionally separate from the process of generating an image based on representations in LTM. Irrelevant visual input is thought to activate representations in LTM, and therefore disrupts performance on tasks that require generation of images such as the peg-word mnemonic, but not tasks that involve temporary visual memory (reviewed in section 1.5.1). Therefore, the workspace model would predict that retaining visual information on a temporary basis will not be disrupted by irrelevant visual input because temporary visual memory and image generation rely on separate cognitive functions. Interference between irrelevant visual input and image generation would be predicted because both processes require the activation of LTM.

5.1 METHOD

Participants and design

Participants were 32 (22 female; 10 male) native English speaking students from the University of Edinburgh. Their average age was 22.19 years (*SD* = 3.75). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in any of the previous experiments. A two-by-two within-subjects design was used; each participant performed both main tasks (retention and generation) in two conditions (control and interference). The order of presentation of tasks and conditions was counterbalanced across participants, with the restriction that they always received both conditions of one task together.

Materials and stimuli

Letter retention task

In the visual short-term retention task, participants had to remember identity, letter case and presentation order of four visually and sequentially presented letters, broadly following the procedure used by Logie et al. (2000). Letters were taken from a set of six visually dissimilar letters with visually dissimilar upper- and lower case forms (Dd; Hh; Ll; Mm; Qq and Rr). They were presented using E-prime, one at a time in Arial font size 24 in the centre of a computer screen for 500ms each, with an inter-stimulus interval of 500ms, followed by a retention interval of 15s. An example display set might therefore be ‘d-M-Q-r’. Case information was indicated in terms of both the visual shape and size of the letters. The possibility of verbal rehearsal of the letters was reduced by articulatory suppression during presentation and retention, with participants repeating the word 'the' aloud at a rate of three times per second. With visual presentation, articulatory suppression is assumed to prevent phonological coding, hence increasing the likelihood of the use of a visual code (e.g. Larsen & Baddeley, 2003). Additionally, participants were explicitly instructed to try and remember the letters visually, by creating an image of the four letters in the correct sequence, and keeping this image in mind. Logie et al. (2000) demonstrated that recall of letters that were visually similar in upper and lower case was poorer than for letters with dissimilar upper and lower case forms, both with and without concurrent articulatory suppression. This visual similarity effect was robust and replicated in different experiments, with visually similar/dissimilar words as well as letters, suggesting the use of a visual code for retention of visually presented verbal sequences.

For this experiment, 36 sequences of 4 letters with mixed upper and lower case forms were constructed (for a full list of letter sequences used see Appendix D). All sequences were constructed such that each letter appeared an equal number of times in its capital and lower-case form, an equal number of times in each serial position and never more than once in each sequence. Furthermore, each letter appeared an equal number of times in the control and in the interference condition. Two completely different versions of this set of 36 sequences were made, and these versions were counterbalanced across participants. Further, 18 sequences in each set were used for the control condition and 18 were used for the dual-task condition, with allocation of stimulus sets to condition counterbalanced across participants.

The participant initiated each trial by pressing the spacebar, upon which a blue screen displayed for one second indicated the start of the trial. Participants were instructed to start articulatory suppression at this point. After presentation of the letters and the retention interval, recall was prompted by a tone and a red screen. Participants stopped articulatory suppression and were requested to recall the letters by writing them on the response sheet in the sequential order and the case in which they were presented. This sheet contained 4 boxes arranged horizontally, with a horizontal line drawn through the centre of each box to avoid ambiguity as to whether a letter was written in its lower-case or upper-case form, and participants were instructed to use the line in this way. On top of the response sheet was also an example box with each of the letters (in both case forms) that were used in the experiment, as they appeared on the screen.

Letter imaging task

The procedure for the letter imaging task was identical to that in Experiment 3. Each of the trials in both conditions consisted of the auditory presentation of 13 letters, at a rate of about 1 letter per second. Participants had to mentally imagine, and make speeded judgments about visual features of the letters, on the basis of a different criterion in each trial (see Appendix C). Three different versions of combinations of letters and criteria were created, and these were counterbalanced across participants.

Irrelevant visual input

The interference task involved viewing a display of dynamic visual noise, adapted from Quinn and McConnell (e.g. 1996b; 2006; McConnell & Quinn, 2000; 2004). The DVN display was presented in the middle of a computer monitor on a black background. Dot size was 4x4 screen pixels (with the screen settings on 600x800 pixels). The display measured 80x80 dots (320x320 screen pixels), positioned centrally on screen. The dot ratio of black and white dots was 50/50, and the display change rate was set at 320 dots plotted per second. The DVN display was presented during performance on the entire trial of the letter imaging task, and in the retention interval of the letter retention task.

Procedure

Participants were tested individually in a quiet room with a minimum of irrelevant visual stimuli. They were seated at a large desk with two computer monitors next to each other, both at a distance of about 50cm, in front of them. Stimuli of the letter retention task were presented on the monitor on the right, and the DVN display on the monitor on the left. Stimuli in the letter imaging task were presented through speakers next to the participant. The experimenter sat next to the participant throughout the experimental session to check compliance with the task-specific instructions and to score performance on the letter imaging task. All trials were self-paced by the participant and initiated by pressing the spacebar. Participants received two practice trials before each condition of the retention task, and one practice trial before each condition of the generation task. Time for recall was unlimited in the retention task.

In the retention interval of both conditions (control and interference) of the letter retention task, participants were instructed to switch looking from the right- to the left-sided monitor as soon as the fourth letter had disappeared. In the interference condition the DVN display was then presented on the left screen, whereas a white screen was displayed in the control condition. The experimenter started and stopped the DVN display in each interference condition trial, to ensure that DVN had no effect on encoding or retrieval of the letters, and was only presented during the retention interval. In the letter imaging task, participants looked at the left-sided monitor in both conditions, and did not need to switch between monitors. In the control condition, the screen was white, whereas on the interference trials, DVN was displayed throughout the duration of the trials. In both trials, the total duration of presentation of the DVN display in the interference condition was 15s.

5.2 RESULTS

Retention and generation task

Performance on the letter retention task was taken as the mean proportion (out of 4) of correctly recalled letters in correct case and serial position in each trial. For the letter generation task performance was taken as the mean proportion (out of 13) of correct judgments in each trial. Mean data are given in Table 5.1.

Table 5.1. Mean performance levels on the letter retention task and the letter image generation task in both conditions

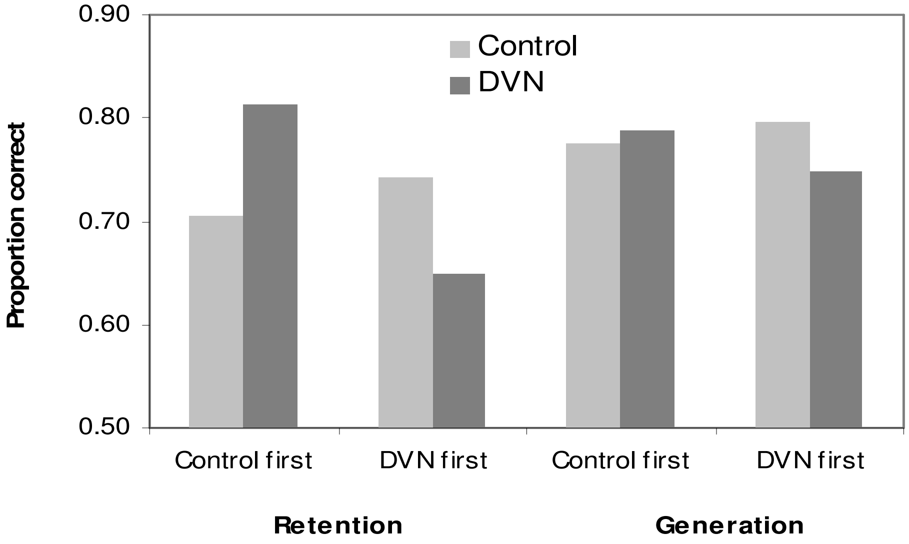
	Control		**DVN**	
	M	*SD*	*M*	*SD*
Retention	.72	.18	.73	.17
Generation	.79	.09	.77	.10

Performance levels for both tasks were well below ceiling and above floor, and were very similar to each other. The interference effect of DVN was tested in a repeated measures ANOVA with condition (control versus interference) and main task (retention versus generation) as within-subjects variables. This analysis revealed no main effect of condition, $F(1,31) = 1.40$, $p = .25$, a significant main effect of task, $F(1,31) = 1171.36$, $p < .001$, and no interaction between task and condition, $F(1,31) = 1.61$, $p = .21$. Separate ANOVA's confirmed that there was no difference in performance between conditions of the letter retention task, $F(1,31) = .04$, $p = .84$, or between conditions of the letter imaging task, $F(1,31) = 2.52$, $p = .12$.

Effect of presentation order

The effect of presentation order of the two conditions on performance levels of both tasks was also investigated. Mean performance levels on both tasks analysed separately for participant groups who received different presentation orders of the conditions are shown in Figure 5.1.

Figure 5.1. Mean performance on the letter retention task and the letter generation task, analysed separately for different presentation orders of the conditions



For the letter retention task, a two-by-two ANOVA with condition (control versus DVN) as within-subjects variable and presentation order of conditions (control first versus DVN first) as between-subjects variable, revealed no main effect of condition, $F(1,31) = .06$, $p = .80$, and no main effect of order, $F(1,31) = 1.36$, $p = .25$, but a significant interaction between order and condition, $F(1,31) = 16.12$, $p < .001$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed a difference between conditions, both for participants who received the control condition first, $p = .014$, and for participants who received the DVN condition first, $p = .032$. This means that participants who received the control condition of the letter retention task first, performed better in the interference condition, whereas participants who received the interference condition first, performed better in the control condition.

A similar pattern of findings was true for the letter image generation task. A two-by-two ANOVA with condition (control versus DVN) as within-subjects variable and presentation order of conditions (first control versus first DVN) as between-subjects variable, revealed no main effect of condition, $F(1,31) = 3.10$, $p = .09$, no main effect of order, $F(1,31) = .11$, $p = .75$, but a significant interaction effect between order and condition, $F(1,31) = 8.12$, $p < .01$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed a difference between conditions only for participants who received the DVN condition first, $p = .014$, but not for participants who received the control condition first, $p = .45$. Therefore, DVN seemed to have an impact on the letter imaging task when the interference condition was given first, but not when it was given after the control condition.

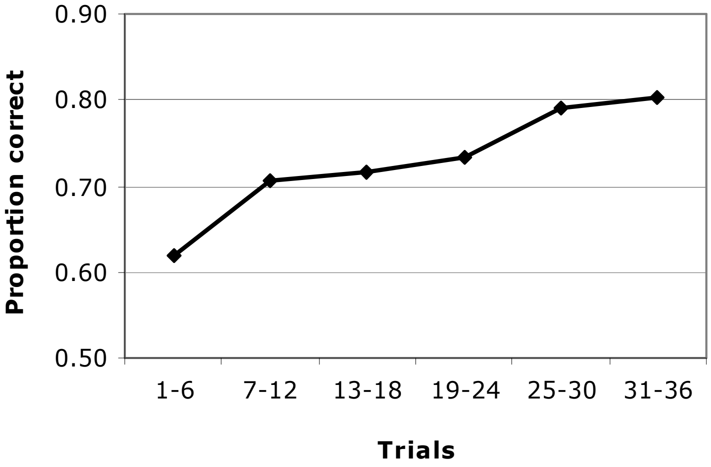
Overall, it seems that performance is better on the condition given second, regardless of whether this is the control or interference condition, suggesting that a learning effect may be swamping any interference effect of DVN in this paradigm.

Learning effect

Because overall, participants seemed to perform better on whichever condition was presented second, the possibility that this reflected a learning effect was further explored for both the retention and generation task. All 36 trials (18 control and 18 interference trials) of the image retention task were subdivided into groups of 6 each, and the mean performance within these trial groups was calculated for each participant, in the order in which they were presented (across conditions). Mean data are shown in Figure 5.2.

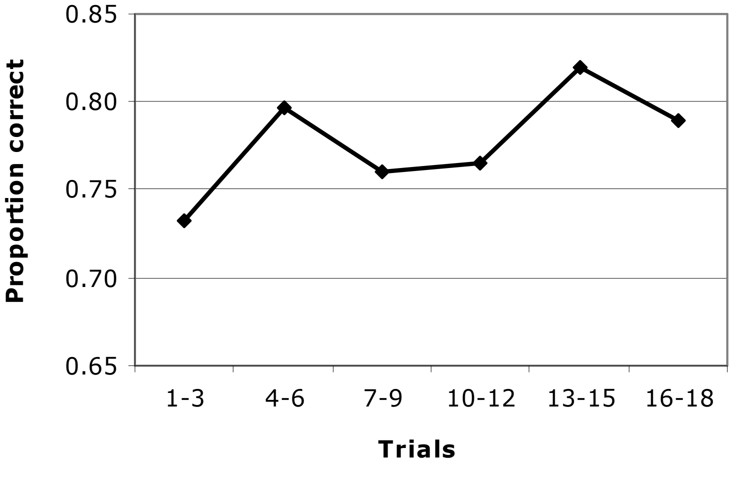
An ANOVA revealed a significant difference in performance between trial groups, $F(5,31) = 6.71$, $p < .001$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed significant differences between the first and each of the further groups of trials (all $p < .05$). There is thus some evidence for a learning effect between the first and second group of trials, but not in any of the consequent trials.

Figure 5.2. Mean performance levels on the letter retention task, separate for groups of 6 trials each



A similar analysis was carried out for the letter image generation task, by subdividing all 18 trials (9 control and 9 interference trials) in groups of 3 and calculating the mean performance within these trial groups, for each participant in the order in which they were presented (across conditions). Mean data are shown in Figure 5.3.

Figure 5.3. Mean performance levels on the letter imaging task, separate for groups of 3 trials each



An ANOVA revealed a significant difference in performance between trial groups, $F(5,31) = 3.80$, $p < .005$. Post-hoc paired-wise comparisons using Newman-Keuls tests revealed a significant difference between the first two groups of trials, $p = .032$, and between the first and fifth group of trials, $p < .005$. Therefore, like in the retention task, there seems to be some learning across trials in the image generation task.

5.3 DISCUSSION

There was no significant effect of DVN on either the image retention task or the image generation task, contrary to the predictions of the workspace model. The gateway model would also have predicted some interference of DVN at least with the retention task, given that all perceptual input has direct access to the working memory system. The unitary model could possibly account for the results by assuming that DVN does not pose any demands on attentional resources. Again, this is a post hoc explanation of the data; no clear predictions could be made from the unitary model. Moreover, the failure to demonstrate an effect of DVN on the image generation task in this experiment is inconsistent with the many findings in literature of disruption of imagery tasks by DVN (Andrade et al., 2002; Baddeley & Andrade, 2000; Dewhurst et al., 2004; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996a, 1996b, 1999, 2006; Smyth & Waller, 1998). One possible explanation for the failure to replicate these effects in the present experiment is that the learning effect in the tasks may have obscured any small effects that DVN may have had. The learning effect was revealed by the analysis of the effect of presentation order of conditions. Participants appeared to perform better on the condition that was given second; regardless of whether this was the control or interference condition. The presence of learning effects was confirmed when mean performance levels across trial groups were compared. From informal verbal feedback of participants, it appeared that many were searching for the best strategy throughout the tasks. Strategy development and switching may thus have contributed to this learning effect.

Another possible explanation for the lack of impact of DVN on the image generation task is that this task did not place sufficient demand on the cognitive resources, enabling participants to 'block out' the interfering effects of DVN. Feedback of participants confirms this idea: some participants reported that watching the display "did not bother them while performing the tasks", and some even reported that they found it "easier to concentrate while focusing on the display, than while trying to look somewhere on a white screen". Therefore, the experimental design might not have been sensitive enough to reveal an effect of DVN.

The previous findings of interference by DVN (see section 1.5.1) have mainly been observed in tasks such as the pegword mnemonic, which could be argued to be a far more demanding task than the letter imaging task. The pegword mnemonic requires participants to generate and retain complex images. Performance levels on the letter imaging task, however, are well below ceiling, and the learning effect confirms the absence of a ceiling effect in performance.

A third possible explanation for the absence of clear effects of DVN in this experiment is that DVN may not have placed a high enough demand on the LTM activation process to disrupt the image generation task. DVN probably activates LTM to a certain degree, because participants may automatically try to make sense of an otherwise meaningless display by trying to match the changing display with known objects, patterns or images in LTM. However, DVN may have been too unstructured or meaningless to place a demand on the LTM activation process sufficiently to disrupt the letter imaging task. In this experiment, the change rate of DVN was set at 320 dots per second (i.e. a 5% change rate). McConnell and Quinn (2000) demonstrated that the effect of DVN increased with an increasing rate of change. The change rate in this experiment may thus not have been rapid enough to result in a disruptive effect. The letter imaging task also requires the activation of LTM, to generate mental visual images of the letters. However, letters are very familiar and relatively simple representations. Therefore, it could be argued that the letter imaging task does not place a high enough demand on the LTM activation process either. The pegword mnemonic, which has repeatedly been demonstrated to be disrupted by DVN, depends more heavily on the activation of LTM, for the generation of more complex visual images.

Experiment 5 was designed to investigate this last possibility by replacing DVN as the perceptual interference task by another perception task that is likely to more reliably involve LTM activation, namely viewing irrelevant concrete pictures. Irrelevant pictures have also repeatedly been demonstrated to interfere with visual imagery (e.g. Andrade et al., 2002; Logie, 1986; Quinn & McConnell, 1996b).

CHAPTER 6

Experiment Five

In Experiment 5, the possibility was explored that no interference was found in Experiment 4 because DVN did not pose a large enough demand on the LTM activation process to disrupt the image generation task. In the present experiment, the same letter retention task and letter imaging task were combined with viewing irrelevant pictures. Concrete line drawings of common objects and animals were used. These are thought to involve the extensive activation of material in LTM, more than does DVN. The workspace model would therefore predict a greater disruption of the generation task by irrelevant pictures than by DVN.

6.1 METHOD

Participants and design

Participants were 24 (16 female; 8 male) native English speaking students from the University of Edinburgh. Their average age was 21.83 years (*SD* = 2.96). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in any of the previous experiments. Design was identical to that in Experiment 4. A two-by-two within-subjects design was used; each participant performed both main tasks (retention and generation) in two conditions (control and interference). The order of presentation of tasks and conditions was counterbalanced across participants, but they always received both conditions of one task together.

Materials and stimuli

Stimuli and procedure of the letter retention and letter imaging task were identical to those in Experiment 4. The only difference was that in this experiment, the interference task was presented on the same computer monitor as the letter retention task stimuli. Therefore, participants did not have to switch monitors and were instructed to always look at the same computer screen. This screen was white in the control conditions. The auditory stimuli of the letter imaging task were presented with a different computer using Power Point, but this computer was out of sight, apart from the speakers which were placed next to the participant, and the key board, to initiate the trials. All trials were self paced.

Stimuli for the interference task were line drawings from the Snodgrass and Vanderwart (1980) picture set. In each trial, a series of 13 pictures was presented using E-prime, for 300ms each with an inter-stimulus interval of 700ms. Pictures started after an interval of 1s and there was a 1s interval after the last picture, resulting in a total duration of 15s for each trial. Pictures were presented in the middle of the computer screen on a white background, and were between 10cm and 15cm in width and height. The presentation of the pictures in the interference condition of the letter imaging task coincided with the auditory presentation of the letters. In the interference condition of the letter retention task, the pictures were presented in the 15s retention interval.

Procedure

The procedure was identical to that in Experiment 4. In the interference condition of the letter imaging task, participants had to press the space bars of two key boards simultaneously, to start presentation of the letters on one computer and of the irrelevant pictures on the other. Participants received two practice trials before each condition of the retention task, and one practice trial before each condition of the generation task. The experimenter was seated next to the participant throughout the experimental session to check compliance with the task-specific instructions and score performance on the letter generation task.

6.2 RESULTS

Retention and generation task

Scoring and analyses of performance were similar to those in Experiment 4. Mean performance levels of both tasks in both conditions are given in Table 6.1.

Table 6.1. Mean performance levels on the letter retention task and the letter generation task, in both conditions

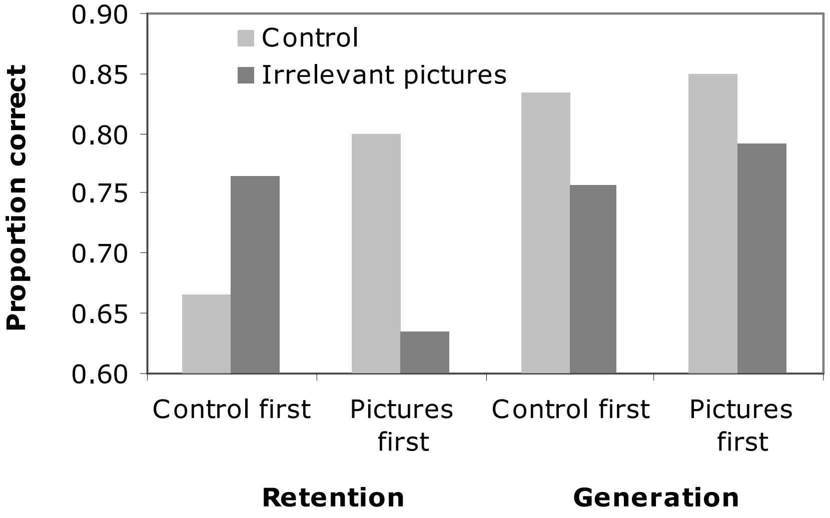
	Control		**Pictures**	
	M	*SD*	*M*	*SD*
Retention	.73	.18	.70	.18
Generation	.84	.07	.77	.09

The interference effect of irrelevant pictures was tested in a repeated measures ANOVA with condition (control versus interference) and main task (retention versus generation) as within-subjects variables. The analysis revealed a main effect of condition, $F(1,23) = 20.87$, $p < .001$, a main effect of task, $F(1,23) = 1117.31$, $p < .001$, and an interaction between task and condition, $F(1,23) = 6.18$, $p = .021$. Post-hoc pair-wise comparisons using a Newman-Keuls test revealed that the difference between conditions was strongly significant for the letter imaging task ($p < .001$), and not significant for the letter retention task ($p = .54$).

Effect of presentation order of conditions

Because an effect of presentation order of conditions on performance in both tasks was found in Experiment 4, this was also tested in the present experiment. Mean performance levels on both tasks, separate for the two different presentation orders of conditions, are shown in Figure 6.1

Figure 6.1. Mean performance levels on the letter retention task and the letter generation task for the different presentation orders of the conditions



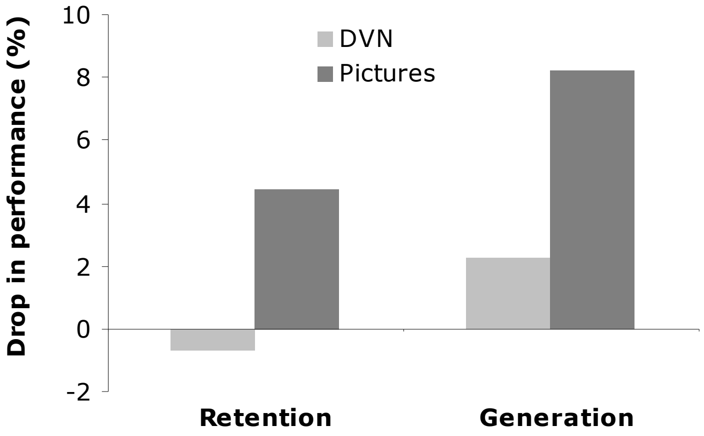
For the letter retention task, a two-by-two ANOVA with condition (control versus interference) as within-subjects variable and presentation order of conditions (first control versus first interference) as between-subjects variable, revealed no main effect of condition, $F(1,23) = 1.90$, $p = .18$, no main effect of order, $F(1,23) = .001$, $p = .97$, but a significant interaction effect between order and condition, $F(1,23) = 29.48$, $p < .001$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed a difference between conditions, both for participants who received the control condition first, $p = .009$, and for participants who received the interference condition first, $p < .001$. This means that participants who received the control condition of the retention task first, performed better in the interference condition, whereas participants who received the interference condition first, performed better in the control condition. That is, there appeared to be an effect of learning but not an effect of irrelevant pictures.

For the letter imaging task, a two-by-two ANOVA with condition (control versus interference) as within-subjects variable and presentation order of conditions (first control versus first interference) as between-subjects variable, revealed a main effect of condition, $F(1,23) = 15.27$, $p = .001$, no main effect of order, $F(1,23) = .91$, $p = .35$, and no significant interaction between order and condition, $F(1,23) = .26$, $p = .61$. Participants thus always performed better in the control condition than in the interference condition of the letter image generation task, independently of the presentation order of conditions.

Comparison of Experiment 4 and 5

Because the designs were identical for experiments 4 and 5, the results were compared statistically, treating type of secondary task interference as a between-subjects variable. The drop in performance (i.e. the difference between performance in the control and interference conditions, as a percentage of performance in the control condition) for both tasks and types of interference, is shown in Figure 6.2.

Figure 6.2. The drop in performance for both tasks and both types of interference



The effect of the two types of interference on the letter retention task was analysed in a two-by-two ANOVA with secondary task (DVN versus irrelevant pictures) as between-subjects variable and condition (control versus interference) as within-subjects variable. This analysis revealed no main effect of condition, $F(1,23) = .34$, $p = .56$, no main effect of interference type, $F(1,23) = .07$, $p = .79$, and no significant interaction between these two variables, $F(1,23) = .71$, $p = .40$. There is therefore no evidence that DVN and irrelevant pictures disrupted performance on the letter retention task.

The same analysis was carried out for the letter imaging task, revealing a main effect of condition, $F(1,23) = 19.05$, $p < .001$, no main effect of interference type, $F(1,23) = 2.13$, $p = .15$, and a significant interaction, $F(1,23) = 6.52$, $p = .013$. Post-hoc pair-wise comparisons using Newman-Keuls tests revealed a significant difference between the two conditions with irrelevant pictures as secondary task, $p < .001$, but not with DVN as secondary task, $p = .41$. This indicates that the interference is driven by irrelevant pictures, not by DVN.

6.3 DISCUSSION

Irrelevant pictures significantly disrupted performance on the image generation task but not on the image retention task. The interference effect of irrelevant pictures with the generation task contrasts with the lack of an effect of DVN in Experiment 4, supporting the hypothesis that DVN may not have placed a strong enough demand on the LTM activation process. The irrelevant picture effect on the generation task was present for both groups of participants; those who received the control condition first, and those who received the interference condition first. In the letter retention task, participants performed better in whichever condition was given second, possibly reflecting a learning effect. In Experiment 4, participants always performed better in the second condition of both main tasks. The disruptive effect of irrelevant pictures in the present experiment thus appeared stronger than the learning effect on the generation task. These results are consistent with previous findings showing that irrelevant visual input disrupts visual imagery based on long-term memory representations, but not visual short-term memory (e.g. Andrade et al., 2002).

The gateway model can not readily account for this data pattern; the results suggest that irrelevant perceptual input does not have direct access to visual working memory, where it would disrupt retention of other items to-be-remembered. The unitary model could account for the results post-hoc by assuming that the image generation task is more attention demanding than the image retention task. The generation task would thus be more susceptible to interference from any attention demanding secondary task. The workspace model also predicted an effect of irrelevant pictures on the generation task, because both involve the activation of LTM. These two different accounts cannot be distinguished on the basis of the results of the present experiment alone. The account of the results in terms of different demands on attentional resources of the retention and generation task is plausible. It could be argued that the generation task requires more attention because the trial-specific task instructions constantly have to be kept in mind, and because the letters follow each other in very quick succession. Moreover, the process of activating representations in LTM could be argued to require more attention than does retention. The account of the workspace model, however, is consistent with findings that the effect of irrelevant visual input appears to be selective for imagery but not for temporary memory tasks (e.g. Andrade et al.; Logie, 1986; Quinn and McConnell, 1996b).

One way to demonstrate the specificity of the effect of irrelevant pictures is by demonstrating a double dissociation with another interference task; a task that selectively disrupts the retention task but not the generation task. Experiment 6 was designed in an attempt to demonstrate such a double dissociation.

CHAPTER 7

Experiment Six

In Experiment 6 the accounts for the results of Experiment 5 that were offered by the workspace and unitary model were tested by contrasting the interference effect of irrelevant pictures with that of unseen figure-of-eight tapping. This task has been demonstrated to significantly disrupt a visual short-term retention task in Experiment 2 (in which a rationale for using this task as such was provided). In the present experiment, a finger tapping task was used instead of the foot tapping task, due to technical difficulties with the foot tapping device, as well as the fact that foot tapping appeared physically strenuous for many participants. The unitary model would predict that tapping is more disruptive of the generation task than of the retention task, on the basis of the results of Experiment 5, which suggested that the generation task was more demanding of attentional resources than the retention task. In contrast, the workspace model would predict a selective disruption by tapping of the retention task, but not the generation task. Within the workspace model the generation task does not pose a heavy load on WM, but mainly involves the activation of long-term representations and generation of images, and there is no requirement to maintain the images in memory. This would predict little, if any, disruption of the generation task by tapping. However, the memory task requires the retention of a sequence of items that have to be recalled by writing them in correct sequential order horizontally from left to right on a response sheet. This might involve a visual code for the appearance of the letter (upper or lower case and letter shape) and a spatial-sequential code for retaining the order. The tapping task is unseen and therefore requires retention of the spatial layout of the keys and updating in visual working memory of which keys have been/have yet to be pressed to maintain the figure of eight pattern. As such the workspace model would predict disruption by a concurrent tapping either because of its requirement to maintain a visual pattern and/or because of its spatial nature.

7.1 METHOD

Participants and design

Participants were 24 (14 female; 10 male) native English speaking students from the University of Edinburgh. Their average age was 19.83 years (*SD* = 1.01). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in any of the previous experiments. Design was identical to that in Experiment 4 and 5. A two-by-two within-subjects design was used; each participant performed both main tasks (retention and generation) in two conditions (control and interference). The order of presentation of tasks and conditions was counterbalanced across participants, but they always received both conditions of each task together.

Materials and stimuli

Stimuli and procedure of the letter retention task and the letter imaging task were identical to those in Experiment 4 and 5. The spatial tapping task involved unseen finger tapping in which participants had to tap in a figure-of-eight pattern. The tapping apparatus used was a square wooden board measuring about 20cm in width, with 9 square buttons in a 3-by-3 array. The buttons each measured approximately 2cm in width. Participants were instructed to tap with only one finger of their preferred hand, at a rate of 2 taps per second. They were not allowed to look at their hand while tapping and had to look at a blank computer screen. The tapping board was connected to a computer which recorded both the sequence of keys tapped and the inter-tap intervals.

Procedure

The procedure was identical to that in Experiment 4 and 5. Participants were tested individually in a quiet test room. They were seated at a large desk with a computer monitor in front of them at a distance of about 50cm. The tapping board was placed out of sight next to the participant, on the side of the preferred hand. The tapping task was performed throughout interference trials of the letter imaging task, and in the retention interval of interference trials of the letter retention task. In the interference condition of the letter retention task, tapping was commenced after presentation of the fourth letter, which was indicated by a sound cue. This sound cue was also present in the control condition, to cancel out the possibility that the sound interferes with the main task. A change of colour on the screen indicated the end of the 15s retention interval, at which point participants had to stop tapping in the interference condition, and for both conditions to recall the letters. All trials of the retention and generation task were self-paced and started by pressing the spacebar. Participants received two practice trials before each condition of the retention task, and one practice trial before each condition of the generation task. The experimenter sat next to the participant throughout the experimental session to check compliance with the task-specific instructions and score performance on the letter imaging task.

7.2 RESULTS

Retention and generation task

Performance levels on the retention and generation task were analysed as in Experiment 4 and 5. The measure of performance was taken as the mean proportion correct in each trial. Mean data are given in Table 7.1.

Table 7.1. Mean performance levels on the letter retention task and letter generation task, in both conditions

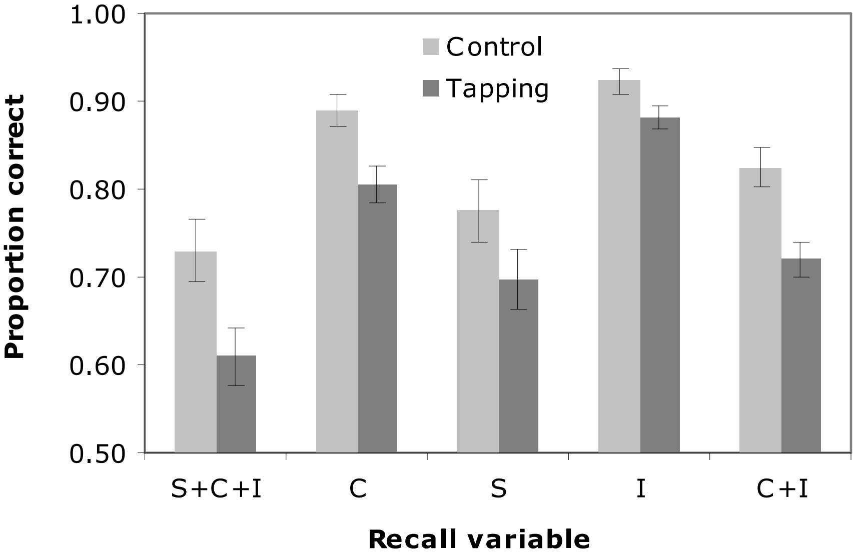
	Control		**Tapping**	
	M	*SD*	*M*	*SD*
Retention	0.73	0.17	0.61	0.16
Generation	0.76	0.08	0.76	0.08

The interference effect of tapping was tested in a repeated measures ANOVA with condition (control versus interference) and main task (retention versus generation) as within-subjects variables. The analysis revealed a main effect of condition, *F*(1,23) = 4.65, *p* = .042, a main effect of task, *F*(1,23) = 1146.03, *p* < .001, and an interaction between task and condition, *F*(1,23) = 6.94, *p* = .015. Post-hoc pair-wise comparisons using a Newman-Keuls test revealed that the difference between conditions was only significant for the retention task (*p* < .005), but not for the generation task (*p* = .62).

Effect of tapping on the letter retention task

In Experiment 5, there was no interference effect of irrelevant pictures on the retention task. However, given the impact of tapping on the letter retention task in the present experiment, the interference effect was further examined by looking at three different measures of recall performance: (1) recall of letter identity, (2) recall of letter case, and (3) recall of serial order of presentation of the letters. These specific recall performance levels in the control and interference condition of the letter retention task are shown in Figure 7.1.

Figure 7.1. Mean performance on the retention task for different variables of recall, in both conditions. C = letter case, I = letter identity, S = serial order



Recall of letter case independently of letter identity was significantly affected by concurrent tapping, *F*(1,23) = 25.21, *p* < .001, as were recall of letter identity independently of serial position and letter case, *F*(1,23) = 9.85, *p* = .005, and recall of letter case combined with letter identity, *F*(1,23) = 22.73, p < .001. The impact on recall of serial order of the letters, independently of letter case, was marginal, *F*(1,23) = 4.20, *p* = .052.

Tapping task performance

Tapping performance was analysed on the basis of three measures: (1) accuracy of maintaining the correct pattern of tapping, (2) accuracy of maintaining the correct overall speed of tapping, and (3) the constancy of speed of tapping. Errors in the accuracy of tapping pattern were omissions or extra taps in the pattern, or reversals in the direction of tapping. A measure for the speed of tapping was the mean of between-tap intervals across trials. Constancy of speed of tapping was measured by taking the standard deviation of between-tap intervals across trials. Mean data are given in Table 7.2.

Table 7.2. Mean number of tapping errors, mean speed (in s) and mean constancy of speed (in s) of tapping, in the letter retention task and the letter generation task

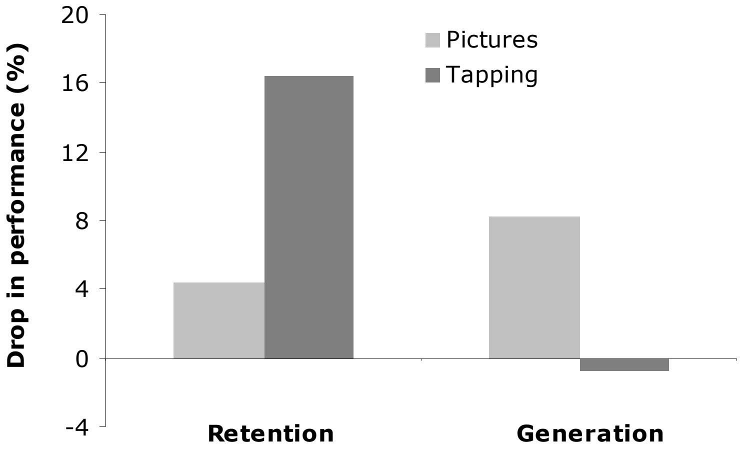
	Tapping errors		**Speed**		**Constancy of speed**	
	M	*SD*	*M*	*SD*	*M*	*SD*
Retention	8.92	12.68	0.49	0.19	0.08	0.04
Generation	7.13	9.32	0.44	0.15	0.10	0.04

The mean number of errors made in the tapping pattern did not differ between the retention task and the generation task, *F*(1,23) = .94, *p* = .34. The tapping speed was very close to the instructed speed of 0.5s per tap, and did not differ between tasks either, *F*(1,23) = 2.42, *p* = .13. There was a significant difference between tasks in the constancy of speed, *F*(1,23) = 4.95, *p* = .036, indicating that tapping was a bit more irregular during the generation than during the retention task.

Comparison of Experiment 5 and 6

Because the designs were identical for experiments 5 and 6, the results were compared directly, treating type of secondary task interference as a between-subjects variable. The drop in performance (i.e. the difference in performance between conditions as a percentage of performance in the control condition) for each task and type of interference is shown in Figure 7.2.

Figure 7.2. The drop in performance levels for both tasks and types of interference



An overall three-way ANOVA with main task (retention versus generation) and condition (control versus interference) as within-subject variables, and interference task (irrelevant pictures versus tapping) as between-subjects variable, revealed a significant three-way interaction, $F(1,23) = 12.55$, $p = .001$. This means that the effect of irrelevant pictures was larger in the image generation task, whereas the effect of tapping was larger in the image retention task. The retention task and generation task thus show a double dissociation of interference from tapping and pictures.

7.3 DISCUSSION

Tapping significantly disrupted visual short-term retention but not image generation. This result is consistent with the predictions of the workspace model, as well as with previous findings (e.g. Andrade et al., 2002). There was a possible account from the unitary model for the results of Experiment 5 if it is assumed that the image generation task is more demanding of limited attentional resources than is image retention. However this cannot account for the results of the present experiment, suggesting that letter retention was prone to interference but image generation was not. The unitary model is thus able to give an account for the results of *either* Experiment 5 *or* Experiment 6 by hypothesising that one task is more attention demanding than the other. This explanation runs into difficulty when considering the combined results of both experiments, which suggest differential selective effects rather than general interference effects. The present results are consistent with other findings of the selective nature of interference of irrelevant visual input on image generation (see Section 1.5.1). Logie (1986), for example, demonstrated a double dissociation of selective interference of irrelevant line drawings on list recall using the pegword mnemonic, and of irrelevant speech on list recall using the rote rehearsal. Quinn and McConnell (1996b) replicated this double dissociation using DVN instead of irrelevant pictures. The unitary model has difficulty accounting for such a selective interference effect.

The combined results of Experiment 5 and 6 are also inconsistent with a model in which visual short-term retention and visual imagery rely on the same ‘working memory gateway’ since the tapping task does not involve any perceptual input, so would not be expected to disrupt either task, while irrelevant pictures ought to disrupt performance on both tasks

The workspace model can readily account for the results from both Experiments 5 and 6. It proposes that irrelevant perceptual input in Experiment 5 disrupted image generation because both involve the process of activation of LTM representations, and compete for this cognitive resource. At the same time, in this model temporary visual representations are thought to be retained in visual WM, independently of the perceptually driven activation of LTM. The workspace model can account for the effect of tapping on visual short-term retention in the present experiment by assuming that both keeping the tapping pattern in mind and maintaining the letters relied on visuo-spatial WM. The fact that performance levels of the tapping task did not differ much between the retention and generation task (participants tapped with the same overall speed, and made equally many errors in keeping to the pattern) undermines the possibility that participants sacrificed tapping performance in favour of the generation task. There was more variability in tapping during letter imaging than during letter retention. This could be attributed to possible response output conflicts, given that letter imaging required an oral response for each letter and this might have slightly delayed some of the tapping responses, rather than any conflict at the cognitive processing level. The workspace model did not predict an impact of tapping on the generation task, because the generation task mainly involved the activation process of LTM, which is assumed to be independent of maintenance in WM.

A possible alternative explanation for the results of Experiments 5 and 6 is that the retention task could be seen as involving a requirement to remember the spatial arrangement of the upper-case and lower-case letters and the spatial serial aspect of presentation, whereas the generation task was more focused on visual appearance, pointing to a spatial-visual distinction. This could explain the sensitivity of the retention task to concurrent tapping (which was also argued to be more spatial than visual in nature in Experiment 2), and of the generation task to the irrelevant pictures. This account for the results is not very likely, however, because both the retention and generation task dealt with the same type of stimuli and were based on the visual features of these stimuli, and the letters for retention were presented one at a time in the same location on the screen. Moreover, in the retention task, tapping appeared to interfere with those variables of recall which involved primarily visual features, specifically letter identity and case-form, and this was driving the overall effect of tapping on retention performance. The feature that could be seen as more spatial, the serial order of the letters, showed a marginal effect, and it is possible that retention of serial order could have been supported in part by time sharing between subvocal rehearsal and suppression. Figure-of-eight tapping could thus be said to mainly affect the visual aspects of the retention task. This is in line with the predictions of the workspace model; the tapping task draws on visual WM to maintain the tapping pattern, and thus interferes with the visual retention of the letters.

One concern with the figure-of-eight tapping task is that in the letter retention task, it had to be carried out simultaneously with articulatory suppression. The instructed rates of the tapping and articulatory suppression were different, namely 2 times per second and three times per second respectively. It appeared very difficult for participants to maintain two asynchronous rhythms, and in fact, many participants were not able to dissociate the two rhythms. Most participants synchronised both rhythms, and either started tapping at a rate of three times per second, or started repeating “the” at a rate of two times per second. Attempting to maintain two independent rhythms in the interference condition of the retention task might have increased the processing load. This hypothesis is consistent with the results of a study by Henson, Hartley, Burgess, Hitch, and Flude (2003), who found that a regular tapping task can interfere with short-term retention when it is externally paced at a specific non-harmonic rate, as opposed to a tapping task that is self-paced. They argue that if tapping is self-paced, participants can adjust their rate of tapping to (a harmonic of) the presentation or rehearsal rate (Henson et al., 2003). In the current experiment, participants were instructed to not adjust their tapping rate to the articulatory suppression rate, and were reminded of this throughout the experiment even when they had difficulty preventing this synchronising. The effort of trying to maintain two non-harmonic rates may have resulted in the disruption of performance on the retention task as compared to the control condition. In the generation task there was not such a requirement to maintain asynchronous rhythms, even though in this task, there was a requirement to respond to each letter as it was presented in addition to generating a tapping response. The interpretation in terms of an effect of maintaining asynchronous rhythms does not explain the complete lack of an impact of tapping on letter imaging, given that letter imaging was sensitive to irrelevant pictures (a procedure that required no response by the participant) in Experiment 5. However, the asynchronous rhythms might have been an important factor in the presence of interference by tapping on the letter retention task in Experiment 6, and this possibility was addressed in Experiment 7.

CHAPTER 8

Experiment Seven

Experiment 7 was designed to further explore the precise effects of tapping on the retention task, and to test the hypothesis that the asynchrony of the rates of articulatory suppression and tapping may have contributed to the interference effect found in Experiment 6. To this aim, the effects of the figure-of-eight tapping task were compared with the effects of a syncopated tapping task (i.e. tapping an elaborate rhythm on one key, with one finger), both without concurrent articulatory suppression. The workspace model would predict a replication of the effects of figure-of-eight tapping on recall performance of the visual features of the letters (i.e. identity and case form), even in the absence of articulatory suppression as had been shown by Logie et al. (2000). This model would assume that the letter retention task relies on visuo-spatial working memory, and could interpret the effect of tapping as being due to the common load on visual WM.

A syncopated tapping task is thought to require more attentional resources than regular spatial tapping, and is thought to specifically interfere with serial aspects of recall (e.g. Saito, 2001). Syncopated tapping has been demonstrated to disrupt recall of visually presented letter strings, and more specifically, to remove the phonological similarity effect (e.g. Larsen & Baddeley, 2003; Saito 1994). Saito argued that syncopated tapping specifically disrupts the activity of the phonological loop (e.g. Saito, 2001). He suggests that the articulatory control process involves some form of speech motor programming or planning, and that speech motor programming deals with rhythmic aspects of speech. When the speech motor programming is used for rhythmic tapping, it cannot control the phonological loop for serial recall of letter materials. Verbal serial recall is thus disrupted by concurrent syncopated tapping because these two processes both rely on a common basic timing system (Saito, 2001). Larson and Baddeley (2003) demonstrated that the effect of syncopated tapping was similar to the effect of syncopated articulatory suppression, and that equal interval tapping on one or multiple keys did not have the same disruptive effect. They argue that syncopated tapping has its effects because it is more attention demanding, and interferes with phonological encoding of the letters (Larsen & Baddeley, 2003). This is consistent with an hypothesis of Mayville et al. (2002), who argue that syncopation, like synchronisation, is organised on a cycle-by-cycle basis, thereby imposing much greater preparatory and attentional demands. Henson et al. (2003) did not replicate the removal of the phonological similarity effect in list recall, but did demonstrate the disruption of recall of serial order of visually presented verbal items by syncopated tapping. Furthermore, they demonstrated a larger effect of syncopated tapping on serial recall than on item recall. Their interpretation of these results is that there is a separation between processes supporting verbal short-term memory for the identity of items and processes supporting memory for their serial order, the latter based on a type of timing signal.

Therefore, although different interpretations have been offered, results of these studies converge to suggest that syncopating tapping disrupts the serial recall of visually presented verbal material in short-term memory tasks. The workspace model would thus predict that the effects of syncopated tapping would dissociate from the effects of pattern tapping; syncopated tapping is predicted to specifically interfere with the recall of serial order of the letters, whereas pattern tapping is predicted to specifically disrupt the recall of visual features (identity and case form) of the letters. Demonstrating a dissociation of effects of the two different tapping tasks on the visual and spatial aspects of the retention task would strengthen the account of the workspace model for the selective effect of figure-of-eight tapping on the retention task in Experiment 6, and would argue against an interpretation of the effect of tapping as a general attention related effect.

8.1 METHOD

Participants and design

Participants were 18 (14 female; 4 male) students from the University of Edinburgh. Their average age was 20.89 years (*SD* = 1.91). They were recruited via the University employment website, and were paid a small honorarium for taking part. None of the participants took part in any of the previous experiments. A within-subjects design was used, with all participants performing the letter retention task in three different conditions; (1) a control condition, (2) concurrent with the figure-of-eight pattern tapping task, and (3) concurrent with a syncopated tapping task. The presentation order of conditions was counterbalanced across participants.

Materials and stimuli

Letter retention task

The letter retention task used in this experiment was a slightly modified version of the retention task used in Experiments 4-6, in that no concurrent articulatory suppression was required. However, from pilot work, it was found that participants performed close to ceiling on this version of the task. Therefore it was decided to increase the number of letters in each trial from 4 to 5, and this avoided ceiling effects in the pilot participants. Also, the total number of letters that the lists were constructed from was reduced from 6 to 5 (i.e. D, H, N, Q, and R, in their upper and lower case forms; the letter L was taken out), increasing the possibility of proactive interference across trials, making it more demanding. Each letter thus appeared once in every trial. It also removed the importance of recall of letter identity, allowing to focus on the clearly visual (i.e. letter case) and spatial (i.e. serial order) features of the task in the analysis. Furthermore, the letter M was replaced by the letter N. This was decided on the basis of a by-letter analysis of recall performance of Experiment 6; it appeared that participants made more errors in recall of case of the M/m than of any of the other letters, possibly reflecting a visual similarity effect. The upper and lower case forms of the letter N are more visually dissimilar. Visual dissimilarity of letters was maximised to encourage encoding of letters (especially case information) in terms of their visual shapes.

Three lists of 18 trials (including 2 practice trials), one for each of the three conditions, were created (see Appendix E). Each letter appeared equally often in its upper and lower case and equally often in each of the 5 serial positions within the trials in each list. Furthermore, an equal number of upper and lower case letters appeared in each serial position within the lists. The lists were counterbalanced across the different conditions, and presentation order of conditions was counterbalanced across participants. Presentation order of the three lists was thus also counterbalanced across participants. Presentation of the lists was similar to the procedure in Experiments 4 – 6: letters were presented visually and sequentially using E-prime, for 500ms each, with an inter-stimulus interval of 500ms, followed by a retention interval of 15s. Because no articulatory suppression was required in this experiment, the blue and red screens before presentation of the letters and after the retention interval (which functioned as cues to start and stop the suppression) were removed.

Tapping tasks

Procedure and instructions for the figure-of-eight tapping task were identical to those in Experiment 6. The syncopated tapping task was carried out on only one of the keys of the 3 x 3 tapping board, with one finger of the preferred hand. The tapping rhythm and procedure were identical to one of the complex rhythms used by Larsen and Baddeley (2003). The rhythm consisted of long (L) intervals of 500ms and short (s) intervals of 250ms. These were also used by Saito (1993, 1994). Participants repeated the following rhythm throughout the retention period: L – s – L – s – L – L – s – L – s – L and were given ample time to learn this rhythm before starting the experimental trials. A computer recorded both the sequence of keys tapped and the inter-tap intervals in both tapping tasks.

Procedure

Participants were tested individually in a quiet room with a minimum of irrelevant visual stimuli. They were seated at a large desk, with a computer monitor at about 50cm distance in front of them, and the computer key board directly in front of that. The tapping board was placed next to the computer key board, on the side of the participants' preferred hand. A black fixation point appeared in the middle of the computer screen after presentation of the fifth letter in each trial, indicating the start of the tapping task in the two tapping conditions. Participants were instructed to tap as long as the point was on the screen (i.e. 15s) and to keep looking at the point while performing the tapping task. An additional sound cue at the end of the retention interval of the retention task (when the fixation point disappeared) indicated the end of the tapping task, and start of recall.

All retention task trials were self-paced by the participant and initiated by a spacebar press. Participants received two practice trials in each condition, and were only allowed to start the tapping conditions when they were able to carry out the tapping tasks on their own flawlessly. The experimenter sat next to the participant throughout the experimental session to check compliance with the task-specific instructions. The experimenter also monitored and gave feedback about performance on the tapping tasks, to ensure that the correct pattern or rhythm and correct tapping speed were maintained throughout the conditions.

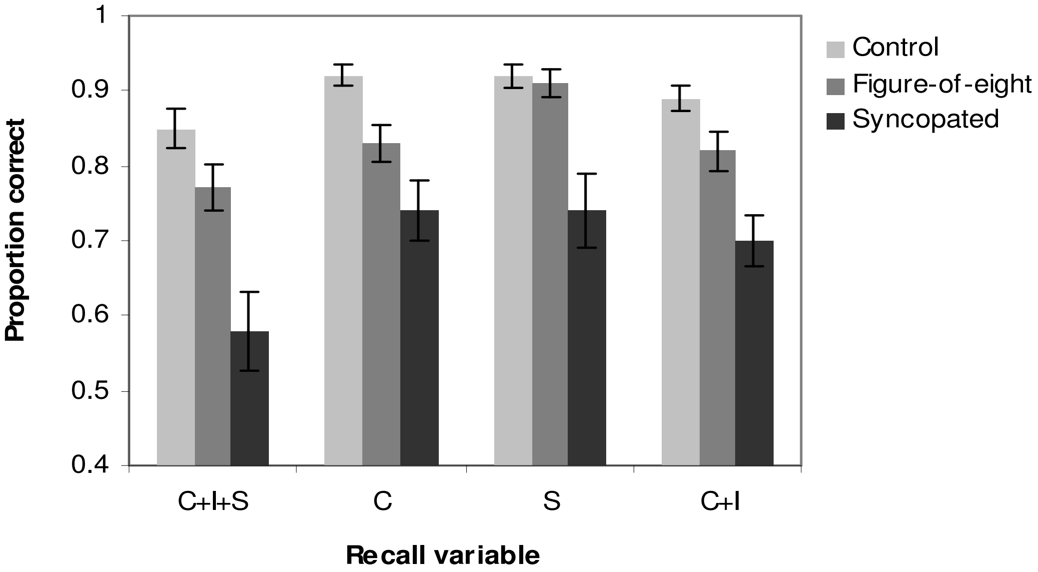
8.2 RESULTS

In total 4 participants had to be replaced: three because their performance in the control condition was at ceiling, and one because the participant performed more than 2.5 times the standard deviation below the mean performance of the group.

Letter retention task

The specific interference effects of the two tapping tasks were investigated as in Experiment 6, by looking at three different measures of recall performance: (1) recall of letter identity, (2) recall of letter case, and (3) recall of serial order. The recall performance levels in the control and both tapping conditions are shown in Figure 8.1.

Figure 8.1. Mean performance on the retention task for different variables of recall, in the three conditions. C = letter case, I = letter identity, S = serial order



For the overall performance, measured as correct recall of identity, case and serial order of the letters, a within-subjects ANOVA revealed a significant difference between conditions, $F(2,16) = 24.17$, $p < .001$. Post-hoc pair-wise comparisons using a Newman-Keuls test revealed a difference between the control and figure-of-eight tapping condition, $p = .043$, between control and syncopated tapping condition, *p* < .001, and between both tapping conditions, *p* < .001.

Recall performance of letter case only (independently of letter identity) also differed significantly between conditions, *F*(2,16) = 17.00, *p* < .001. Post-hoc pair-wise comparisons revealed a difference between the control and figure-of-eight tapping condition, *p* < .01, between control and syncopated tapping condition, *p* < .001, and between both tapping conditions, *p* < .01.

Recall performance of serial order, independently of case form, differed significantly between conditions, *F*(2,16) = 12.59, *p* < .001, but post-hoc comparisons revealed that only the syncopated tapping condition differed significantly from both the control condition, *p* < .001, and the figure-of-eight tapping condition, *p* < .001. The figure-of-eight tapping condition did not differ from the control condition, *p* = .87.

Finally, the difference between conditions in recall performance of letter case and identity, independently of serial order, was also significant, *F*(2,16) = 26.57, *p* < .001. Post-hoc tests revealed that the difference between each of the individual conditions was significant: control versus figure-of-eight tapping, *p* < .01, control versus syncopated tapping, *p* < .001, and figure-of-eight tapping versus syncopated tapping, *p* < .001.

The different recall performance levels in the control condition and figure-of-eight tapping condition were also compared directly in an overall 2 x 4 repeated measures ANOVA with condition (control, tapping) and recall performance (case + serial order + identity, case, serial order, case + identity) as within-subjects variables. This analysis revealed a two-way interaction between condition and recall performance, *F*(3,15) = 10.82, *p* < .001. Post-hoc pair-wise comparisons using the Newman-Keuls test revealed a difference between the two conditions in recall of the combination of case, serial order and identity, *p* < .001, in recall of case only, *p* < .001, and in recall of case and identity, *p* < .001. The only difference that was not significant was the difference in recall of serial order, independently of case, *p* = .82.

The same overall ANOVA was carried out for the control and syncopated tapping condition, which also revealed a significant two-way interaction, *F*(3,15) = 4.58, *p* < .01. Post-hoc tests revealed that each of the recall measures differed significantly between the two conditions (all *p* < .001).

Figure-of-eight tapping task

Performance on the figure-of-eight tapping task was analysed on the basis of the between-tap interval times only. Errors in the accuracy of the tapping pattern were not analysed because in Experiment 6 it was demonstrated that participants made very few errors (on average fewer than 9 errors across all trials). Moreover, when looking at the tapping performance of individual participants in Experiment 6, it appeared that only 4 participants made many errors (i.e. more than 15), and most participants (14) made fewer than 5 errors. The 4 participants that made many errors seemed to make most of these errors in the first three trials. In the present experiment, participants received 2 practice trials instead of 1, which reduced this effect of making errors in the first few trials. Moreover, in the present experiment participants were thoroughly trained on both tapping tasks to ensure they were able to maintain the correct tapping pattern perfectly, before starting the experimental trials. Their tapping performance was also monitored (and corrected if necessary) by the experimenter throughout all trials. The accuracy of maintaining the correct overall speed of tapping (measured as the mean of between-tap intervals across trials) and the constancy of speed of tapping (measured as the standard deviation of between-tap intervals across trials) of participants are given in Table 8.1.

Table 8.1. Mean speed (in s) and mean constancy of speed (in s) in the figure-of-eight tapping task

	M	**SD**
Speed	0.44	0.12
Constancy	0.06	0.02

The mean tapping speed was somewhat faster than the instructed 2 taps per second (i.e. a mean between-tap interval time of 0.50s), but was overall very constant, fluctuating on average only 60ms from the mean speed. These performance levels were also very similar to those of the figure-of-eight tapping during the letter retention task in Experiment 6, in which participants tapped with a mean speed of 0.49 per tap, and a constancy of 0.08s.

Syncopated tapping task

For the syncopated tapping task, accuracy of maintaining the correct overall speed of tapping, and the constancy of speed of tapping, were analysed separately for the short- and long tapping intervals of the tapping rhythm. Mean data are given in Table 8.2.

Table 8.2. Mean speed (in s) and mean constancy of speed (in s) for short and long intervals of the syncopated tapping task

	Short		**Long**	
	M	*SD*	*M*	*SD*
Speed	0.31	0.06	0.62	0.13
Constancy	0.03	0.01	0.07	0.05

The mean length of both short and long intervals was a little longer than the instructed speed of 0.25s for the short intervals, and 0.50s for the long intervals. The mean constancy of tapping speed was very high again, both for short and long intervals.

8.3 DISCUSSION

The impact of the figure-of-eight tapping task on recall performance on the letter retention task of Experiment 6 was replicated in this experiment. In both experiments, the pattern tapping significantly affected recall of the combination of letter identity, case and serial order, recall of case independently of identity, and the combination of case and identity, independently of serial order. Furthermore, in both experiments, the figure-of-eight tapping task did not have an effect on recall of the serial order of letters, independently of case. Pattern tapping thus affected all measures of recall that consider letter case – the mainly visual feature of the task – whereas it did not affect serial recall, which, in this case was most likely based on subvocal rehearsal in the absence of articulatory suppression. In contrast, the syncopated tapping task affected all measures of recall, including serial order independently of letter case. It was expected that the syncopated tapping task would mainly affect recall of serial order, on the basis of previous findings (e.g. Henson et al., 2003; Larson & Baddeley, 2003; Saito, 1994). The large non-specific impact of the task suggests that it is a more attention demanding task than the figure-of-eight tapping task, and that its effects may be due to the increase in general processing load. There was no reason to suspect that participants had sacrificed performance on either of the tapping tasks for the benefit of performance on the letter retention task; mean speed and consistency of speed were very accurate in both tapping tasks.

The selective interference effects of the figure-of-eight tapping task on the visual features of letter retention are consistent with the predictions of the workspace model – i.e. the pattern tapping task requires visuo-spatial WM to keep track of the tapping sequence and to maintain the pattern of tapping in mind, and the common requirement for this component causes the disruption of maintaining the letters. These results also speak against the alternative offered hypothesis, that the figure-of-eight tapping task in Experiment 6 had its impact on the retention task because of the difficulty to maintain the two different, inharmonious rhythms of the articulatory suppression and the tapping. In the present experiment, participants were not required to engage in articulatory suppression, and only had to maintain one speed, that of the tapping task. The tapping task still had the same impact, suggesting that its interference effects were selective.

CHAPTER 9

Implicit Semantic Processing in Neglect

9.1 ACCOUNTS OF THE THREE MODELS

Section 1.4.1 discussed a number of specific problems associated with the gateway model of the interaction between working memory and long-term memory. It appeared that interpreting the fact that perceptual information can be processed without the subjective conscious experience of perceiving that information, presents a challenge to this model. In particular, the phenomenon of implicit *semantic* processing (as demonstrated, for example, in patients with perceptual neglect) creates a problem. The fact that semantic information about visual stimuli can be available even when these stimuli have not been consciously perceived, suggests that LTM (the semantic knowledge base) has been activated, without the stimuli being represented in WM (e.g. Della Sala & Logie, 2002; Logie, 1995; 2003). As discussed in Section 1.4.1, the gateway model could only account for this by assuming an extra, fast track for perceptual information directly to LTM. Such a 'leaky gateway model', however, is less parsimonious than the unitary or workspace model (e.g. Della Sala & Logie, 2002).

The workspace model and the unitary model can more readily account for the phenomenon of implicit semantic processing. The unitary model would interpret implicit processing as the successful activation of LTM traces that remain outside the focus of attention (and thus consciousness), but that are still part of WM and can have an influence on behaviour (e.g. Cowan, 1980, 1999). In the workspace model, in normal perception, the activation of LTM makes the information available for construction of a visual mental representation in WM (e.g. Logie, 1995). Implicit semantic processing of visual stimuli would then reflect the activation of LTM, combined with a failure to generate a conscious image in WM. The activated LTM traces are sufficient, however, to influence behaviour (e.g. Della Sala & Logie, 2002; Logie, 2003; Weiskrantz, 1997). In this way, the workspace model could interpret implicit semantic processing of visual stimuli by neglect patients as the degraded or incomplete activation of LTM by visual perceptual input from their contralesional visual field, due to their attention deficit. The weak or incomplete activation of LTM may result in an incomplete or degraded representation of the visual information in WM, and may account for the lack of awareness that neglect patients have for the visual information in their affected visual field. The activation of LTM traces, however, is sufficient to allow for appropriate behavioural responses in the absence of conscious awareness of the reasons for doing so (Logie, 1995). Consistent with this interpretation, Farah (1994) argued that neural representation is not all or none: completed processing of a stimulus (to derive a high-quality representation) may not be necessary for the visual system to pass some information on to subsequent levels of processing. Degraded or incomplete visual perceptual input will therefore presumably activate, to some degree, conceptual and semantic LTM representations (Farah, 1994).

Experiment 8 in this thesis was designed to demonstrate implicit semantic processing of visual material in patients with perceptual neglect. This would argue against a view in which all perceptual input has direct access to the WM system, as proposed by the gateway model. Implicit processing is studied in patients with perceptual neglect, because this is covered by a large body of literature, and because this type of implicit processing lends itself well to experimental investigation. Section 9.2 will provide a review of studies that have attempted to demonstrate implicit visual processing in neglect patients and in Section 9.3 the neural substrate for implicit processing in neglect will be discussed.

9.2 LITERATURE REVIEW

As mentioned, there is a large literature on behavioural studies attempting to demonstrate implicit processing of visual stimuli in neglect and extinction patients. Extinction is a condition similar to neglect, and occurs when a person is able to report or respond to a stimulus presented in isolation but unable to report this same stimulus, presented simultaneously with another stimulus (usually on the other side of the body) (Heilman et al., 1993). Various studies have demonstrated, for example, that processes that are considered to take place ‘pre-attentively’ in the normal system, can still occur for neglected visual input. Neglect patients have been shown to be able to detect the presence of visual stimuli (Mijović-Prelec, Shin, Chabris, & Kosslyn, 1994), have intact figure-ground segregation (Driver, Baylis, & Rafal, 1992), perceive meaningful continuity in a stimulus array (Kartsounis & Warrington, 1989), group visual features together (Vuilleumier, Valenza, & Landis, 2001b) and process colour and shape of stimuli (Grossi, Correra, & Calise, 1995; Karnath, 1988), all without being consciously aware of the stimuli. Some studies have demonstrated that neglected verbal stimuli can sometimes be processed to a level of lexical representation (i.e. abstract letter identity) (e.g. Audet, Bub, & Lecours, 1991; Fuentes & Humphreys, 1996; Schweinberger & Stief, 2001). Many studies have provided evidence that neglect patients can also still process visual stimuli to a higher level of visual analysis (i.e. to a level of semantic representation) without conscious awareness. Demonstrations of implicit semantic processing of neglected stimuli support the workspace model's interpretation of implicit processing as the activation of LTM without a representation in WM. These studies have used various paradigms, such as same-different judgement tasks, semantic priming tasks, the 'burning house' paradigm, perception of chimeric stimuli and reading tasks. In the following review, some relevant studies from each of these different paradigms, and their findings, are discussed.

9.2.1 Same-different judgements

In same-different judgement tasks, patients are typically presented with pairs of horizontally aligned visual stimuli and have to judge whether these are the same or not. Awareness for the left-sided items is then tested by means of a separate identification or detection task. When there is a discrepancy in patients' ability to detect or name the left-sided stimulus, and their same-different judgements, then they could be said to have processed the left-sided items implicitly. One of the first studies to use this paradigm was a study by Volpe, LeDoux and Gazzaniga (1979). Four patients with extinction were able to indicate whether two pictures or words were the same or different in more than 90% of trials, while performing poorly on the naming test. Volpe et al. claimed that the extinguished stimuli were processed implicitly to a level of object identification, on the basis of which the same/different judgments were made. With this paradigm, however, it is possible that the patients may have relied on lower-level visual characteristics of the stimuli rather than on their activated semantic representations. Indeed, a repetition of the experiment with meaningless pictures and nonsense syllables instead of pictures and words did not change the pattern of results (Volpe et al., 1979), supporting the interpretation that the same/difference judgments were not made on the basis of their semantic representations. Berti et al. (1992) addressed this issue using the same paradigm of demonstrating a dissociation between identification and same/different judgments of horizontally aligned photographs of objects, but manipulated the semantic and visual relatedness of the two items. In pairs in which the two items were the same, they could either be identical, or could show the same object photographed from different viewpoints, or with different objects from the same category. A patient with extinction, EM, performed above chance on the same-different judgement task, even when 'same' items were not visually identical, and despite her naming performance for left-sided items being very poor. These data suggest that EM's judgements were not based on low-level visual characteristics alone, and that she analysed the visual stimuli to a level of object identity and category.

A problem with these two studies is that there was no formal direct comparison between the patients' same-different judgement performance and their identification performance. An important issue in studying implicit processing is the reliable demonstration of an absence of conscious awareness (or explicit processing) for the stimuli. Two general classes of measures for conscious awareness can be used: subjective and objective measures (Dienes, 2004; Merikle & Cheesman, 1986). Subjective measures of awareness rely on participants' self-reports of their perceptual experiences or conscious processing. Objective measures rely on a participant's ability to discriminate between particular stimuli, such as in forced-choice judgment or detection tasks. Measures of objective awareness provide a lower threshold for conscious awareness than subjective measures. Both in Volpe et al's (1979) and Berti et al's (1992) experiments, only a subjective measure of awareness was used (free identification of stimuli), and the argument could be made that this does not reliably demonstrate an absence of conscious awareness of the stimuli. There is a possibility that although patients reported that they could not see or name the stimuli, they may still have perceived part of the stimuli, but felt insufficiently confident to report their presence (e.g. Hannula, Simons, & Cohen, 2005; Reingold & Merikle, 1990). Verfaellie, Milberg, McGlinchey-Berroth, and Grande (1995) used an objective measure (a forced-choice identification task), rather than a subjective measure (free naming task), to assess the awareness of neglect patients for the left-sided items in pairs, and manipulated the visual similarity between items in the stimulus pairs. To examine if the judgement performance exceeded the identification performance, their identification of left-sided stimuli was compared directly with their judgement performance. For a subgroup of patients, the left identification performance was at chance level (52%) whereas their same/different judgment performance was above chance and significantly higher than the identification performance. There was no effect of visual similarity on the accuracy of the judgments of these patients. Therefore, even if two items were visually similar, they were able to detect a difference between the two items at a semantic level.

9.2.2 Semantic priming

Another paradigm that is frequently used to study implicit semantic processing is that of semantic priming. In these studies, patients are presented with visual primes before having to make certain judgements about target stimuli, which can be semantically related or unrelated to the prime. For example, McGlinchey-Berroth, Milberg, Verfaellie, Alexander and Kilduff (1993) presented four neglect patients with a prime picture either in the left or right visual field, followed by a centrally presented word or non-word letter string, and patients had to make a word/non-word decision with a key press. Three of the four patients responded significantly faster when primes were semantically related to the words than when they were unrelated. These priming effects were similar for left and right-sided primes. In a forced-choice identification task, similar primes were presented, followed by a recognition display of the prime picture with a visually and semantically unrelated foil. Performance of the three patients in this identification task was at chance for primes presented on the left, but above chance and significantly better for primes on the right. These results suggest that the left-sided primes were processed implicitly to a semantic level in the word/non-word task. McGlinchey-Berroth, et al. (1996) replicated these results for words and non-word primes instead of picture primes. In this study, patients also demonstrated significant *negative* priming by words that were orthographically similar to words that are semantically related to the target word, but only when these primes were presented in the left visual field. These results suggest that orthographic representations generated for neglected word stimuli are sufficiently specified to provide the basis for lexical encoding and subsequent semantic activation, but not enough to influence performance in the identification task. Implicit semantic processing by neglect patients using similar priming paradigms was also demonstrated by Berti and Rizzolatti (1992), Esterman et al. (2002), Kanne (2002) and Làdavas, Paladini, and Cubelli (1993).

9.2.3 Burning house paradigm

A third paradigm used to investigate implicit semantic processing in neglect patients is a paradigm first employed by Marshall and Halligan (1988) in their ‘burning house’ study. It typically involves a forced-choice judgement task with vertically aligned pairs of visual stimuli that differ only on the left side, combined with a measure to demonstrate a lack of awareness for this difference. Marshall and Halligan (1988) presented neglect patient PS with a vertically aligned pair of line drawings of identical dark green houses, one of which had bright red flames emerging from a window on the left side. They randomly alternated the position of the 'burning house' in the pair. Upon each presentation, PS was first asked to indicate whether the two houses were 'same' or 'different' and to indicate in which of the two she would prefer to live. On all 21 trials she never noticed the flames and indicated that the two houses were exactly the same, or made remarks such as "that one is slightly bigger". Despite her failure to notice any difference between the two houses, PS was then asked in which house she would prefer to live. She commented that this question was a "silly question, because they're the same". When forced to make a response, she selected the non-burning house on 17 trials (81%), well above chance. It could be argued that the neglected flames implicitly activated semantic representations of fire and its negative consequences, leading to the correct picture selection. However, a possible alternative explanation for these results is that PS's selections were perceptually and not semantically based. The presence of low-level sensory properties of the stimuli, such as the colour of the flames, its complexity, symmetry, or a lack of good continuation or closure, may have determined her preference judgements rather than the knowledge that flames are dangerous or destructive (Humphreys & Riddoch, 1993; Làdavas et al., 1993). This hypothesis is supported by studies that have failed to replicate the clear findings of Marshall and Halligan using the same paradigm (e.g. Bisiach & Rusconi, 1990; Cantagallo & Della Sala, 1998; Doricchi, Incoccia, & Galati, 1997). Bisiach and Rusconi (1990), for instance, presented four neglect patients with the burning house pair, and three additional black and white picture pairs (a complete and broken glass, a complete and torn banknote, and a vase with or without flowers), always with the difference between items of a pair on the left. Overall, patients consistently preferred the logically correct item in three cases (two patients for the unbroken glass, and one for the vase with flowers), but in two cases they selected one item in a pair at random (once the houses, and once the banknotes), and two patients consistently preferred the logically *incorrect* item in a pair (both the burning house). The variety of responses, and in particular the instances of patients preferring the logically incorrect item, suggests that patients did not extract the meaning from neglected stimuli, but may have based their preference on the presence of visual features (Bisiach & Rusconi, 1990).

Doricchi and Galati (2000) addressed this issue by investigating the role of symmetry of items in the stimulus pairs in the burning house paradigm. They presented neglect patient LP with pairs of line drawings of common objects, one of them with functional damage either on the left or ride side. On trials on which LP failed to detect the difference between items, she indicated to prefer the correct intact item in almost 90%. However, eight out of the ten items were symmetrical without damage, and asymmetrical with damage, and therefore LP's judgements could have been based on the better visual qualities (symmetry) of the undamaged items. In a second experiment, LP was presented with drawings in which the good functional items were always asymmetrical, and the damaged ones symmetrical. She still preferred the correct item in 94% of trials on which she did not notice the difference, indicating that her responses were not influenced by the symmetry of objects, but rather on the semantic content (Doricchi & Galati, 2000).

9.2.4 Chimeric figures

Chimeric figures are visual stimuli in which the left and right halves represent two different objects or animals. It has been demonstrated that neglect patients often fail to report the left side of chimeric pictures and are not aware of the chimeric nature of the figures. They base identification and naming of the figures on the right side only (e.g. Young, Hellawell, & Welch, 1992; di Pellegrino, Frassinetti, & Basso, 1995; Cantagallo and Della Sala, 1998). There is evidence, however, that they can still process the left side of chimeric figures implicitly. Peru, Moro, Avesani, and Aglioti (1997), for example, reported some anecdotal evidence, suggesting that the left of chimeric figures were processed implicitly. Two patients in their study called a picture with a fan on the left, attached to the anterior half of a rooster on the right, a "nice peacock". Similar observations were made in a study by Cantagallo and Della Sala (1998). Their patient, FF, called a squirrel-horse a "horse with a rather heavy back" and a rifle-trombone a "trombone firing notes".

Chimeric pictures thus offer a good tool for the investigation of implicit processing in neglect patients. Vallar, Rusconi and Bisiach (1994), for instance, presented five neglect patients with pairs of line drawings of animals. Pairs consisted of one complete animal (e.g. a dog) and one chimeric animal, of which the right half was identical to the complete animal in the pair (i.e. a half dog) and the left half was the anterior half of another animal (e.g. a half horse). One patient, GS, almost always judged the two items in these pairs as identical, being unaware of the chimeric nature of one of them. When a direct verbal clue referring to the left half of the chimeric item was given (in this example: "Which one is more similar to a horse?"), GS selected the chimeric animal in 75% of the trials. She could thus be said to have processed the left half of the chimeric animals implicitly to a semantic level of representation, allowing her to make a correct decision. However, her responses may also be compatible with a lower level of visual analysis, such as good continuation of the stimuli (Vallar et al., 1994). Buxbaum and Coslett (1994) investigated the role of specific visual characteristics in the perception of chimeric figures, by manipulating the visual and semantic relatedness of the two halves. They found that neglect patients significantly more often failed to identify the left half of chimeric figures when the left side was less visually complex than the right half, compared to when it was more visually complex than the right half. There was also a trend for the left side of a chimeric to be omitted more frequently when it was semantically related to the right half, than when it was unrelated. However, the mechanism underlying improved report of semantically unrelated figures may be similar to that mediating the visual complexity effect, as figures from same semantic categories may be more visually similar, and thus less distinctive. To test this hypothesis, Buxbaum and Coslett (1994) gave patients a forced-choice identification task when they neglected the left half of a chimeric figure. In this task, vertically aligned pairs of two complete figures were presented, the target of which was the whole counterpart to the left side of the chimeric, the foil being a different, but visually similar whole figure. Two patients correctly identified the target significantly above chance in this test, suggesting that they had implicit semantic information available about the left side of the chimeric figures, and that their responses were not simply based on a low-level visual analysis of the figures. Similar results have been obtained by Riddoch, Humphreys, Edwards, Baker, and Wilson (2003), and by Peru et al. (1996; Peru, Moro, Avesani, & Aglioti, 1997). In particular, one patient in Peru et al's (1996) study performed well above chance on deciding whether items in a vertically aligned pair of a whole, and a chimeric figure (which was identical to the whole figure on the right side) were same or different. However, he often failed to recognise chimeric figures explicitly in an identification task, in which figures had to be classified as whole, half or chimeric (i.e. 'odd'), suggesting that he had processed the left half of the chimeric figures implicitly (Peru et al., 1996).

9.2.5 Reading tasks

Some studies have demonstrated implicit semantic processing in reading tasks. Làdavas, Umiltà, and Mapelli (1997), for instance, instructed nine neglect patients to read aloud and make lexical (word/non-word) and semantic (living/non-living) judgments about letter strings. They found a significant dissociation between performance on the reading task and performance on the lexical and semantic judgment tasks. Patients correctly read only about 21% of the letter strings, but their performance on the lexical decision task was 88% correct, and for the semantic judgment task 91%. A simple explanation could be that reading is more difficult than a lexical or semantic judgement, considering the probability of correct guesses. Letters reported in the reading task, although incomplete or incorrect, may have been enough to allow for a good guess about the lexical status and the semantic category of the letter string. To test this possibility, healthy participants were presented with the verbal productions from the patients in the reading task, and had to make the lexical and semantic judgments on the basis of this information. They performed at chance on both tasks, which suggests that the patients may have had more (lexical and semantic) information available implicitly, on basis of which they made the judgments.

In another reading task by Berti, Frassinetti, and Umiltà (1994), neglect patient MD was tested on a stroop paradigm, in which the names of colours or the first few letters of the names were presented in coloured ink that was either congruent or incongruent with the colour name. The remaining letters of the partial words were represented by X's. MD had to read the words and name the colour of the ink. In the reading task, he made frequent omissions of the letters on the left side of each word. His colour naming times, however, were significantly slower in the incongruent condition (for both complete and partial words) compared to the congruent condition. When a control group was presented with a list of words, constructed on the basis of the number of left-sided letters neglected by MD, no stroop effect was observed. These results again suggest that there is preserved semantic processing of the meaning of neglected words and partial words (Berti et al., 1994).

9.2.6 Summary and discussion

Implicit semantic processing by neglect patients appears to be a reliable and robust phenomenon, demonstrated in a range of different paradigms. Patients have been demonstrated to be able to make accurate same-different judgements at a semantic level for horizontally aligned pairs of stimuli, of which they can not overtly identify the left-sided items (e.g. Berti et al., 1992; Verfaellie et al., 1995; Volpe et al., 1979); their reaction time of decision making is influenced by the semantic content of neglected picture or word primes (e.g. Berti & Rizzolatti, 1992; Esterman et al., 2002; Kanne, 2002; Làdavas et al., 1993; McGlinchey-Berroth et al., 1993; 1996); they are able to distinguish items in vertically aligned pairs on the basis of semantic information, without being consciously aware of the left-sided differences between items (e.g. Doricchi & Galati, 2000; Doricchi et al., 1997; Marshall & Halligan, 1988); they can extract semantic information from neglected left halves of chimeric figures (e.g. Buxbaum & Coslett, 1994; Peru et al., 1996; Riddoch et al., 2003; Vallar et al., 1994); and finally, they can implicitly process the semantic content of words they are unable to read completely (e.g. Berti et al., 1994; Làdavas et al., 1997).

Even though implicit semantic processing of neglected stimuli has been demonstrated repeatedly, many studies are characterised by a lack of careful manipulation of visual and semantic properties of stimuli to investigate exactly to which extend neglected stimuli can undergo cognitive processing. For this thesis, the question to which degree stimuli can be processed implicitly is important because it has implications for the interpretation of the phenomenon of implicit processing in terms of cognitive models of working memory. According to the workspace model, implicit processing reflects the activation of LTM representations, without a consequent conscious visual representation in WM being generated from this activated LTM material. Likewise, according to the unitary model, implicit processing reflects the activation of LTM traces, without these entering the focus of attention. In this view, a relatively large amount of information (including semantic representations) should still be available for stimuli that are not consciously perceived. As discussed above, the gateway model would have difficulty to account for *any* high-level processing of information without a representation of this information in working memory. In Experiment 8 in this thesis, it was attempted to replicate the findings of implicit semantic processing, and extend these by investigating whether implicit processing indeed relies on the activation of LTM. To this purpose, the familiarity (and thus the availability of representations in LTM) of the experimental stimuli was manipulated. The workspace and unitary models would predict that when there is a large network of LTM representations available for visual stimuli, these stimuli are more likely to undergo extensive processing, even in the absence of visual awareness (i.e. in the absence of a visual representation in working memory or the focus of attention).

As mentioned above, to reliably demonstrate implicit processing of a visual stimulus, it is very important to demonstrate an absence of conscious awareness (absence of explicit processing) of this stimulus, and the use of the right measure of awareness creates a difficult issue. Using a subjective measure of awareness has been criticised mainly because a patient may still perceive part of the stimulus, but feel insufficiently confident to report this (e.g.

Hannula et al., 2005). An objective measure of awareness, however, has the disadvantage that it may be as sensitive to the presence of degraded visual information as is the measure of implicit processing. An objective measure of explicit processing is in this respect not any different in essence from a measure of *implicit* processing. If a certain task is accepted as a measure for unaware processing, how can it be ensured that this is not actually measuring degraded aware processing? For instance, some studies used a same/different judgement task as the measure of implicit processing, coupled with another measure of aware processing, such as free identification or detection. In other studies, however, a same/different judgement task was used as an objective measure of *aware* processing. One could argue that it is impossible to measure unconscious processing by definition, because showing that performance is above chance on any task demonstrates that the stimuli have been perceived (e.g. Banks & Farber, 2002). The issue of the use of subjective and objective measures of awareness has led to much discussion in literature about the validity of claims of implicit processing. However, in the end, what counts is the subjective experience of participants. When they do not report stimuli, or indicate that they are not consciously aware of something, they can be said to be unaware of the stimuli. When they can then be demonstrated to process the stimuli on a more implicit task, they can be said to have processed stimuli implicitly. Awareness is a state that is not directly accessible by the experimenter, leaving him to rely on the verbal report of the participant, and there is no reason to doubt that a participant would be untruthful in reporting awareness. It seems eminently reasonable that one can demonstrate the absence of conscious awareness through verbal report of participants, and it is generally accepted that neglect patients are truly unaware of the contralateral information that is processed. Therefore, a subjective measure of awareness (i.e. patients' self report) was employed in Experiment 8 in this thesis.

In many of these studies, a group of neglect (or extinction) patients was tested initially, of which only one or a few demonstrated the ability of implicit processing; by far not every patient appears able to process visual stimuli implicitly to a semantic level of representation. This large variability between patients' data is typical for studies on implicit processing by neglect patients, and might be due to differing severities of neglect symptoms and variability of anatomic lesion sites (see also the next section). That there is a relationship between the severity of neglect and the ability to process stimuli implicitly has been demonstrated in several studies (e.g. Peru et al., 1996; Verfaellie et al., 1995). Patients with very severe neglect do not demonstrate any signs of processing, explicitly or implicitly, of left-sided visual stimuli. For some patients their attentional impairments seem to be mild enough to still process a considerable amount of visual stimuli explicitly, making it more difficult to demonstrate implicit processing.

9.3 NEURAL SUBSTRATE OF IMPLICIT PROCESSING

Neglect can result from damage to various right hemisphere regions, in particular the posterior parietal cortex. More precisely, the crucial area appears to be the inferior parietal cortex at the temporo-parietal junction (e.g. Mesulam, 1999). Other areas associated with neglect, although less frequently, are regions in the frontal cortex, the dorsolateral premotor cortex, the superior temporal gyrus, the anterior cingulate cortex, and some subcortical structures (thalamus, basal ganglia and white matter fibre tracts) (Halligan, Fink, Marshall, & Vallar, 2003; Mesulam, 1999; Vallar, 2001). Lesions localised more posteriorly in the occipital regions, or more superiorly in the parietal cortex bring about visual field deficits or a deficit of reaching (optic ataxia), without neglect (Halligan et al., 2003). It has been suggested that the major challenge in the study of neglect and extinction is to explain the loss of awareness itself, given that many visual processing areas are spared (Driver & Vuilleumier, 2001).

The network of brain regions disrupted in many neglect patients often leaves posterior occipital and inferior temporal cortices relatively intact. Neuroimaging studies with neglect or extinction patients have indeed demonstrated that unconscious perception of visual stimuli still results in a relatively broad network of activation, including substantial areas in the visual cortex, as well as some temporal, prefrontal and parietal areas (e.g. Rees et al., 2002; Vuilleumier et al., 2002a). Importantly, category-specific areas of the ventral visual stream still appear to be activated by extinguished stimuli, although this activation is less strong than for consciously perceived stimuli. Although the ventral visual stream has often been suggested to provide a crucial substrate for visual awareness (Milner and Goodale, 1995; Zeki and Bartels, 1999), these data imply that activation of areas in the ventral visual cortex might be insufficient for visual awareness. In these studies, conscious detection was associated both with higher activity in ventral visual areas, and in parietal and frontal areas (Rees et al., 2002).

The key area associated with neglect, the parietal cortex, has been suggested to deal with the association between object identity and location, and the relative position in space and in relation to body parts. This area of the brain receives input not only from the primary visual cortex, but also from the auditory system, the proprioceptive system, the vestibular system, and the somato-sensory system. Moreover, there are projections from areas dealing with information about movement of the eyes, head, limbs, and body. Damage to this area therefore leads to the typical neglect symptoms of impaired spatial representations of the environment in relation to the body (e.g. Driver & Vuilleumier, 2001; Logie, 1995). The role of the parietal cortex in linking spatial with object information also relates to the ability to bind diverse properties coded in different brain areas, a function generally attributed to working memory. Indeed, in Sections 1.3.2 and 1.4.2, some evidence was reviewed to suggest that parietal areas as well as prefrontal areas are very important in working memory (e.g. D'Esposito et al., 1998). The impaired parietal cortex in neglect patients, combined with the reduced activity in prefrontal cortex for unseen stimuli (e.g. Rees et al., 2002), supports the hypothesis that implicitly processed stimuli are not represented in the working memory system in neglect patients. As mentioned above, several authors have suggested that visual awareness may depend on entry into working memory (e.g. Baars, 1997; Crick & Koch, 1995). This could thus explain the lack of awareness for stimuli in neglect patients. At the same time, the activation of ventral occipital and temporal areas could be responsible for the ability to process the stimuli to a level sufficient to allow for appropriate behavioural responses (e.g. Driver & Vuilleumier, 2001). The extraction of identity, category or semantics from LTM for neglected visual objects has indeed been linked to ventral temporal areas (e.g. Driver, 1996).

The ability of individual neglect patients to process stimuli implicitly may depend on the size and site of the lesion. Additional damage to occipital or temporal cortices might compromise the ability to process any visual stimuli, explicitly or implicitly. This hypothesis is supported by studies that have compared performance on behavioural tasks with lesion sites in neglect patients. Vuilleumier et al. (2001b), for instance, found that effects of implicit grouping in Kanizsa figures occurred only in some cases, depending closely on the site of the lesion. Kanizsa figures induce the subjective perception of illusory contours in healthy individuals, due to pre-attentive grouping processes. Patients with a preserved implicit influence of subjective figures had focal brain damage centred on the inferior parietal cortex or thalamus, sparing the occipital lobe. The subjective figure influence was absent in patients whose damage extended posteriorly into lateral occipital cortex. Both groups of patients failed to explicitly detect left-side inducers of the Kanizsa figures in matching judgments, and they showed similar neglect severity on other standard tests (Vuilleumier et al., 2001b).

CHAPTER 10

Experiment Eight

10.1 INTRODUCTION

Experiment 8 was designed to demonstrate implicit semantic processing of visual material in patients with perceptual neglect, to further contrast the three models of the interaction between WM and LTM. Specifically, the gateway model would have difficulty accounting for *any* implicit high-level processing, whereas both the workspace and unitary models would predict that a relatively large amount of information (including semantic representations) should still be available for stimuli that are not consciously perceived (see Section 9.1). This latter prediction was tested in the present experiment, by comparing the success of implicit processing of familiar and unfamiliar visual stimuli.

Study using familiar and unfamiliar proverbs

The present study was based on an unpublished study (cited in Logie & Della Sala, 2004) in which a neglect patient was presented with drawings in which the left side depicted a certain proverb. The patient, GSt, had to select the correct proverb with the picture from a set of six proverbs read out to him. GSt never overtly reported the left side of the pictures, but still selected the correct proverb above chance level. This ability to process the pictures implicitly, however, was only there when the depicted proverbs were familiar British proverbs. In the experiment, there were two conditions; one with familiar English proverbs, and one with translated proverbs from Chinese or Russian. For the British proverbs, GSt selected the correct proverb in 40% of trials (8 out of 20), compared to 20% (4/20) for the unfamiliar proverbs. Chance level was 1/6 = 16.67% correct. He always indicated that his answers were pure guesses, and was not able to give a rational basis for any of his choices. These results were supported by analogous findings in healthy individuals. In this control experiment, the relevant halves of the pictures, containing the clues to the correct proverbs, were presented subliminally and with a mask. The majority of participants performed above chance for both sets of proverbs, but, like GSt, performed significantly better for the familiar than for the unfamiliar proverbs.

Taken together, these results suggest that the neglected (or masked) information from the relevant side of the pictures still activated stored knowledge of familiar proverbs. These results are consistent with other studies that have demonstrated an influence of implicitly perceived pictorial information on decision making processes based on lexical information (e.g. McGlinchey-Berroth et al., 1993; 1996). The difference between performance for familiar and unfamiliar proverbs suggests that for familiar proverbs, the representations of the complete proverbs in LTM were activated; these representations were not available for the unfamiliar proverbs. There is a rich network in the base of stored knowledge of visual, semantic and other representations associated with proverbs that are well known to a person. For unfamiliar proverbs, this coherent representation of the complete proverb itself is absent. This interpretation is thus consistent with the assumption of the workspace and unitary models, that implicit semantic processing relies on the pre-existence of representations in LTM. These models would predict that implicit processing of visual stimuli is more likely when there is a wide network of LTM representations available that can be activated for these visual stimuli, leading to an appropriate behavioural outcome, even if the activation is insufficient for a conscious representation in WM.

Improvements to the paradigm

There are a number of limitations of this study, however. The healthy control participants showed implicit processing for both types of stimuli, familiar and unfamiliar proverbs, even though they performed better for familiar proverbs. The fact that there is also implicit processing for unfamiliar proverbs, for which there is no global representation in LTM, suggests that individual elements from the pictures may have acted as clues to key words in the correct proverb. Implicitly processing these elements may thus already lead to correct proverb selection. This priming of keywords probably plays an important role in the processing of both types of proverbs. Activation of the representation of the key stimuli in the picture might in many cases be sufficient to influence correct proverb selection. For familiar proverbs, however, the key elements in the picture activate the semantic representations of these stimuli in LTM, and the simultaneous activation of all these individual representations could subsequently activate the complete proverb representation. This may have led to the better performance on the task for familiar proverbs. In another control experiment, these key words were removed from the proverbs by paraphrasing the proverbs while preserving their meaning. If selection of both familiar and unfamiliar proverbs indeed crucially depends on processing these key words, performance was expected to be at chance level. It is unlikely that participants will be able to still select the correct proverb on the basis of analysing the meaning of the paraphrased proverb, as this would depend on a very complex elaborate type of priming. This is exactly what was found: in both conditions performance was at chance level, with no significant difference between conditions. It could thus be concluded that performance in the main experiments relied on the presence of key words in the presented proverbs, related to individual visual clues in the pictures.

The fact that GSt and the healthy controls performed better for familiar proverbs, suggests that activation of the representations of the complete proverbs did still contribute to selecting the correct proverbs. In Experiment 8, it was attempted to replicate the findings of these experiments, while controlling for the possibility of implicit processing of key words, which might confound results and make the likeliness of successful performance for familiar and unfamiliar proverbs more equal. To this purpose, foils were included in the proverb lists. These were proverbs with a key word in common with the target proverb. These key words were names of target features in the pictures. With this manipulation it was possible to investigate whether only key elements from pictures were processed, or whether the complete proverb representation was processed. In addition to the target and foil proverb there were two distractor proverbs in each list, which both had no relationship to the picture or the target proverb.

Some additional changes were made to the methodology and procedure, for the present study. The two conditions in the previous study were presented in blocks (2 blocks in each condition, counterbalanced according to a Latin Square design). Blocking the presentation of stimuli of different conditions might lead to a response bias. Therefore, in the present experiment, trials of both conditions were randomised. In the previous experiment all proverbs were presented on paper, and read out twice by the experimenter. Reading out the proverbs might have led to giving subtle verbal hints to the participant by (unintentional) changes in intonation or stressing certain words more in the correct proverb. In the present experiment, all proverbs were recorded digitally by a native English speaking man, who was blind to the experiment and did not know which the correct proverbs were. Sound files of these recorded proverbs were played back to the participants in the experiment, either on a laptop computer or a portable CD player.

Predictions

The workspace and unitary models would predict that in case of the familiar proverbs, the neglected side of pictures might not only lead to implicit activation of key words, but also of complete proverb representations. Therefore, the target proverb is predicted to be selected more often than the foil, and both target and foil more often than the distracters. There are no complete representations of the unfamiliar proverbs in LTM, and therefore the target and foil proverb were predicted to be selected equally often, on the basis of activation of the key words through implicit processing of the target features in the pictures. Target and foil together were also predicted to be selected more often than the distracters.

10.2 MATERIAL

Pictures

Visual stimuli were 48 compound pictures, consisting of scenes of a number of objects and persons, e.g. a boy with an apple and a ball in his left and right hand, and in the background a doctor and a hoop (see Figure 10.1). A full list of all pictures is included in Appendix G. The left half of each picture represented a proverb ("An apple a day keeps the doctor away", in this example), while the right half was completely unrelated to this proverb. Pictures were compiled using material from a range of sources (Corel Gallery; Microsoft Office Clip Art; Snodgrass & Vanderwart, 1980). All items within one picture were images chosen to be of similar style and quality, to maintain the uniformity and consistency of the stimuli. Stimuli ranged in size from 15 to 20 cm in width and height and were printed on A4 paper. They were always in black and white or shades of grey, apart from one left-sided item that functioned as the main clue to the correct proverb (e.g. the apple), and one unrelated right-sided item of similar size and in roughly the same position on the right of the midline (e.g. the basket ball). These two items were always coloured realistically. The set of 48 stimuli was divided into two subsets of 20, one representing common familiar British proverbs, the other unfamiliar foreign (Dutch) proverbs, and a set of eight stimuli (five familiar and three unfamiliar proverbs) that were used in practice trials.

Figure 10.1. Example of a pictorial stimulus depicting a familiar proverb ("An apple a day keeps the doctor away")

To avoid the possibility that participants learned that the left halves of the pictures always contained the clues to the correct proverbs, mirror versions of all stimuli, with the target features on the right side, were created. In each test session, a quarter of all experimental trials (i.e. 10 of the 40 stimuli) were given in mirror version. This manipulation had the additional advantage that the neglect patients' ability to match the correct proverb with pictorial stimuli *that they were aware of*, could be assessed, as a control measure.

Proverbs

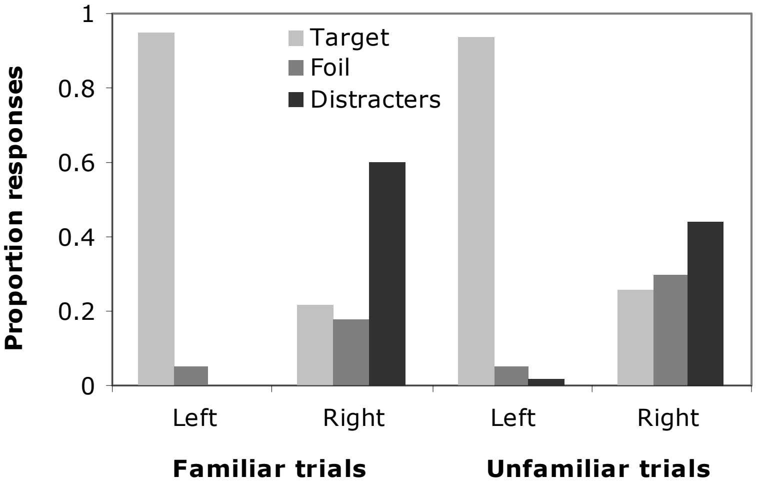
The proverbs presented with each picture were taken from various published collections (Flavell & Flavell, 2004; Miedler & Dundes, 1994; Stoett, 1901) as well as on-line databases (e.g. website of manythings.org; website of ucla.edu). Proverb sets for the familiar proverb pictures were all common British proverbs, sets for the unfamiliar pictures all consisted of Dutch proverbs. The Dutch proverbs were translated literally, and modified where necessary to make them grammatically correct and flow well in English. To create the sets of 4 proverbs for each picture, a foil and two distracter proverbs were selected to match the 40 target proverbs. The foil was a proverb that contained the same key word as the target (e.g. “One rotten *apple* spoils the barrel”, in the above example). The distracters were two proverbs that were completely unrelated to the target and foil, and to the picture. However, the distracters also shared a key word between them, to prevent a response bias of patients to ‘one of the two proverbs that have a word in common’. Each set of four proverbs therefore contained two pairs of proverbs with the same key word. The sets of proverbs were recorded digitally by a male native English speaker who was blind to the aim of the experiment. A full list of all 40 sets of proverbs is included in Appendix H.

Piloting picture halves with healthy elderly participants

Pictures were piloted to test whether the clues in the left half were clear and unambiguous, and whether the right halves were strictly unrelated to any of the four proverbs. Participants were 10 healthy elderly volunteers (6 male, 4 female), recruited from the Volunteer Subject Panel of the Psychology Department of the University of Edinburgh. Their average age was 61.7 (*SD* = 12.3) and they were all right-handed. Their level of education ranged from having finished secondary school to having a university degree. An initial set of 50 pictures was created and pictures were split in half over the vertical midline. The halves were randomly assigned to two sets, with the limitation of each set containing only one half of each picture, as many left as right halves, and as many familiar as unfamiliar pictures. Sets were counterbalanced across participants. Each picture half was printed on A4 paper and presented together with the set of 4 proverbs belonging to that picture, on a different sheet of paper. Participants had unlimited time to view the pictures and read the proverbs. They had to tick a box next to the proverb they thought matched best with the picture. These participants should invariably select the correct (target) proverbs for the left halves of the pictures, but should perform at chance level (25% correct) for the right halves of the pictures. If, in this pilot study, there was no difference between performance for the right halves of familiar and unfamiliar proverbs, then any difference between familiar and unfamiliar proverbs found in the experiment could be taken to reflect the influence of information in the left side of the pictures.

On the basis of a by-picture analysis of the mean data, 40 stimuli from the initial set of 50 were selected for the experiment. Ten pictures were discarded either because participants chose the correct proverb on the basis of the right side more than at chance level, or because participants did not choose the correct proverb on basis of the left side in all cases. (Eight of these ten rejected stimuli were used as practice trials in the experiment). Figure 10.2 shows the mean proportions of responses of each proverb type, within each of four categories of stimuli (left halves of familiar proverbs, right halves of familiar proverbs, left halves of unfamiliar proverbs, and right halves of unfamiliar proverbs), for the selected 40 stimuli.

Figure 10.2. Mean proportion of target, foil and distracter proverbs selected



Because there were only one target and one foil, but two distracter proverbs in each list, the proportions expected on the basis of chance performance would be 25%, 25% and 50% respectively. Chi-square tests revealed that for familiar trials, the responses to the left halves of pictures differed significantly from chance level, $\chi^2(2, N = 100) = 262$, $p < .001$, and so did responses to the left halves of unfamiliar stimuli, $\chi^2(2, N = 100) = 254.46$, $p < .001$. Participants selected the target proverb more often than the foil and distracters when they saw the left halves of pictures.

A 2 (familiar versus unfamiliar) x 3 (target, foil, distracter) chi-square test of independence revealed that there was no difference in the distribution of proportions of proverb selections between left half trials of familiar and of unfamiliar proverbs, $\chi^2(2, N = 200) = 1.01$, $p > .25$. This was also tested with a paired samples t-test, looking at the proportion of correct target responses, which did not reveal a significant difference either, $t(9) = .28$, $p = .79$. Therefore, when participants were presented with the left halves of pictures, they performed equally well in familiar and in unfamiliar trials.

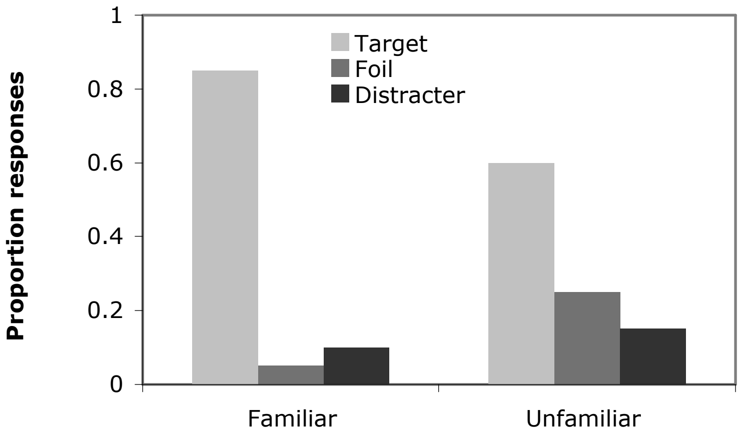
Responses for the right halves of both types of stimuli did not differ significantly from chance level, both for familiar, $\chi^2(2, N = 100) = 4.32$, $p > .10$ and for unfamiliar trials, $\chi^2(2, N = 100) = 1.54$, $p > .25$. Participants thus performed at chance when presented with the right halves of pictures. Again, there was no difference between the distribution of responses to the right half trials of familiar and unfamiliar proverbs, $\chi^2(2, N = 200) = 4.61$, $p = .10$, and as tested with a paired samples t-test, $t(9) = -.61$, $p = .56$. Therefore, when participants were presented with the right halves of pictures, they also performed equally well in familiar and in unfamiliar trials.

Piloting mirror versions of pictures with a neglect patient

In an additional study to pilot the pictorial stimuli, mirror versions of all pictures, with target features on the right side, were presented to a neglect patient. This was to test whether neglect patients are also able to match the correct proverbs with information from the pictures. The patient, FD, was a 70 year old, right-handed woman with severe left-sided neglect. She had a stroke in the middle cerebral artery, affecting large parts of her right cortex with sparing of the basal ganglia. She was tested two days after her stroke, while still on the acute stroke ward, but was able to sit in a chair next to the bed. The diagnosis of perceptual neglect was confirmed by the star cancellation test (a subtest of the BIT, see Section 10.3) on which she cancelled out all 20 stars on the right half, but none on the left. The proportion of her responses on familiar and unfamiliar proverbs is shown in Figure 10.3.

FD was always aware of all right-sided (relevant) items in the pictures, even though she invariably neglected the left halves. She performed significantly different from chance level in both familiar, $\chi^2(2, N = 20) = 294.4$, $p < .001$, and unfamiliar trials, $\chi^2(2, N = 20) = 14.7$, $p < .001$, always selecting the target proverb more often than the foil and distracters. There was no difference in the proportion of target, foil and distracter proverbs selected between familiar and unfamiliar trials, $\chi^2(2, N = 40) = 3.72$, $p > .15$.

Figure 10.3. Proportion of target, foil and distracter proverbs selected by FD



This pilot study thus confirmed the usability of the experimental paradigm with stroke patients, and confirmed the validity of the experimental stimuli. Any difference found in performance between familiar and unfamiliar trials in the experiment, cannot be attributed to differences in the difficulty or clarity of stimuli in these categories, and could be taken to reflect implicit processing of the left of pictures.

One note of caution should be mentioned here: even though this difference is not significant, FD seems to have selected the target proverb more often in familiar (85%) than in unfamiliar (60%) trials. A control group in the experiment consisting of 9 right brain-damaged patients with no neglect, however, did not show this difference between familiar and unfamiliar trials.

Familiarity of proverbs

Participants in the experiment might be more likely to select the (British or foreign) proverb from the set of four that is or seems most familiar to them. To prevent such a bias, sets of four equally familiar proverbs were compiled for each picture, on the basis of a pilot study assessing familiarity of a large set of British and translated Dutch proverbs. Participants were 8 native English speaking members of the Volunteer Subject Panel of the Psychology Department of the University of Edinburgh. All were 50 years or older, and had not taken part in the pilot study for the pictures. All proverbs were arranged in a list, with British and Dutch proverbs randomised. Participants were asked to rate each proverb for familiarity by circling one of three possible scores: (0) for “I don’t know the proverb”, (1) for “I have heard of this proverb, but it is not very familiar to me” or (2) for “I am very familiar with the proverb”. Participants were told that they were not tested on their knowledge of the meaning of the proverbs, but that we were only interested to know how familiar these proverbs were to them. They were furthermore told that some proverbs were British proverbs and that others were translated foreign proverbs.

The average score assigned to the 20 British target proverbs (represented in the pictures) was 1.89 (*SD* = 0.22), and for the 20 unfamiliar target proverbs 0.26 (*SD* = 0.24). A foil and two distracter proverbs were selected to match each target proverb, on the basis of the criterion that their scores should be within one standard deviation away from the score of the specific target. Restrictions were that the foil should have the key word in common with the target and the two distractors should have one word in common.

10.3 PARTICIPANTS

Neglect patients

Four perceptual neglect patients were recruited from the Acute Stroke Unit of the Western General Hospital and the Stroke Rehabilitation ward of the Royal Victoria Hospital, both in Edinburgh. Patients were recruited on the basis of referral by the ward consultants and other medical staff, and by screening medical records of current patients on the wards. All four patients had left-sided perceptual neglect due to a right-sided stroke. Their main demographic and medical information is given in Table 10.1. Images of CT scans of the patients are given in Appendix I to illustrate the site and extent of their stroke.

Table 10.1. Main demographic information of the four neglect patients

	Sex	**Age**	**Educ.**	**Hand**	**Stroke - test (days)**	**Stroke side + site**
CK	M	78	12	L	11	R fronto-temporal
EW	M	72	14	R	87	R middle cerebral artery territory
JL	F	78	12	R	12	R inferior posterior parietal
PM	M	61	11	R	11	R total anterior circulation stroke

Diagnostic test protocol

All neglect patients first took part in a diagnostic test session to confirm the diagnosis of perceptual neglect. A description of the tests and administration and scoring rules of the diagnostic test battery will be given here. This battery included a number of standard diagnostic tests for perceptual neglect, some additional tasks to assess the specific cognitive abilities that are required in the experiment, and tests to rule out visual field defects and other impairments. Results from the diagnostic tests are given in Table 10.2.

Letter Cancellation task

The Letter Cancellation task, Line Bisection task and Line Crossing task are three subtests of the Behavioural Inattention Test battery (BIT, Halligan, Wilson & Cockburn, 1990). These three specific subtests for the diagnosis of perceptual neglect, were selected on the basis of a study by Jehkonen et al. (1998). They investigated which combination of two or three out of six BIT subtests resulted in the best diagnostic sensitivity and specificity. Diagnostic sensitivity was defined as the percentage of neglect patients correctly detected with a test combination, and diagnostic specificity as the percentage of non-neglect patients correctly diagnosed. In their study, patients were diagnosed as having perceptual neglect if they scored below the original cut-off score in at least two of the six subtests, or in one of the two or three tests of a specific combination. From their analysis it appeared that the best combination was a set of three tests: line crossing, letter cancellation and line bisection. This combination failed to identify only one out of 20 neglect patients and misdiagnosed only one non-neglect patient out of a group of 32. Jehkonen et al. (1998) claimed that this test combination is sufficient to detect visual neglect in the acute phase, with a minimum of subtests needed.

In the Letter Cancellation task, patients were presented with a sheet of paper containing five rows of letters (with 34 letter per row). These rows were divided into 4 columns. Ten target letters (‘E’ and ‘R’) were interspersed randomly in each of the columns. Patients were instructed that the page contains many letters and that he/she has to cross out all the E’s and R’s. The examiner illustrated this by crossing out the letters E and R located at the bottom of the stimulus sheet, and told patients to indicate that he was finished by putting down the pen. The maximum score on this task is 40, and cut-off score for the presence of perceptual neglect is 32.

Line Bisection task

In the Line Bisection task, patients were asked to estimate and then mark (in free vision) the mid-point of three 204 mm long horizontal lines. The lines were positioned in three different spatial locations (left, middle and right) on a horizontal A4 paper. The extent of each line was pointed out to patients, who were then instructed to estimate the centre. Deviations from the mark drawn by the patient to the actual midpoint for each line were measured. A score of 3 is achieved if the mark falls within 0.5 inch (1.27 cm) distance from the actual midpoint of the line; a score of 2 if the mark falls between 0.5 and 0.8 inch (2.0 cm) distance from the midpoint; and a score of 1 if the mark was placed between 0.8 and 1.0 inch (2.5 cm) from the midpoint. The total maximum score on this task is nine points, and cut-off score is 7.

Line Crossing task

In the Line Crossing task, patients were presented with an A4 sheet containing 40 one-inch (25.4 mm) long lines in different orientations. The page was placed directly in front of the patient. The lines appeared to be randomly spaced about the page but were in fact grouped into seven columns (containing 6 lines each), three on either side of a central column. The examiner demonstrated the required response by indicating all lines, crossing out two of the four lines located in the central column, and then instructed the patient to cross out all the lines he could see on the page. The total number of lines crossed by the patient was scored, except from the lines in the central column. The maximum score on this task is 36 and cut-off score is 34.

Drawing from memory

The drawing from memory task is another BIT subtest, for representational neglect. In this task, patients were presented with a blank sheet of paper and were asked to draw (1) a large clock face with numbers first, and then the arms indicating 9 o’clock, (2) a simple drawing of a person, and (3) a simple drawing of a flower. The scoring is based on the relative completeness of the respective drawings. Maximum score is 3, cut-off score is 2.

Picture Scanning task

This additional perceptual neglect test assessed the perceptual awareness of patients for visual material similar to the experimental stimuli. Patients were presented with ten compound pictures. They were instructed to describe the pictures and to name all items that they could see. The number of pictures completely described was scored and notes were taken of which left- and right-sided items were omitted in the incompletely described pictures.

Picture Matching task

The Picture Matching task assessed the specific ability required in the experiment, of matching pictorial information with lexical information. This task consisted of three trials that were similar in design and instruction to the experimental trials. Patients were presented with four compound pictures, one at a time. With each picture, patients were read out four sentences, and had to select the one they thought described the picture best. These trials tested patients' ability to keep in mind and compare four sentences, and to match these to a picture in view.

Anosognosia

Anosognosia for hemi-paresis of arm and leg was tested with a questionnaire adapted from Berti, Làdavas, and Della Corte (1996). In this questionnaire, patients were first asked some general questions about their condition and about their arms and legs. For each question, there was a more specific follow-up question if the patient was assessed to be in denial of deficit(s). Two points were given if the patient denied any problem despite a follow-up question, one point if the problem was admitted on the follow-up query, and zero points if the primary question was answered correctly. For both arm and leg, the score may thus range from 0 (no anosognosia) to 2 (moderate-severe anosognosia). The total anosognosia score is the sum of the scores for arm and leg (range 0-4). Additionally, anosognosia for perceptual problems was assessed informally by questioning patients about any visual problems they might have.

Visual field defects/ extinction

Visual field defects were tested by asking patients to detect finger movements in the four quadrants of the visual field, while keeping the eyes fixated on the experimenter, right in front of them. Extinction was tested by means of the *visual confrontation technique* (Bender, 1952). Patients had to detect small short movements of the examiner's index fingers held at eye height about 30cm from them, and about 35-40 degrees left and right from their midline. The specific procedure of the test was adapted from Cocchini, Cubelli, Della Sala, and Beschin (1999). Patients received 20 trials with single (10 left and 10 right) and 10 with bilateral movement, in random order. The cut-off point for extinction was when more than 80% of the single stimuli, but less than 50% of the bilateral stimuli were detected.

Vocabulary

A measure of patients' verbal IQ was their performance on the vocabulary subtest of the third version of the Wechsler Adults Intelligence Scale (WAIS-III). In this test the experimenter read out a list of 33 (increasingly difficult) words and patients were asked to describe the meaning of each word. A score of 0, 1 or 2 was given for each description, depending on how many key words or synonyms were given. Performance was scored by reference to the WAIS-III scoring manual. Maximum score possible is 66.

Table 10.2. Diagnostic test results. A = anosognosia; VFD = visual field defects; E = extinction; PS = picture scanning; LiCr = line crossing; LeCa = letter cancellation; LB = line bisection; PM = picture matching; D = drawing; V = vocabulary; n/t = not tested

	A	**VFD**	**E**	**PS**	**LiCr**[1]	**LeCa**[1]	**LB**[2]	**PM**	**D**	**V**
CK[3]	0	No[1]	no	3	0 - 13	0 - 15	2	3	3	27
EW	0	no	yes	4	0 – 11	0 – 6	0	3	2	45
JL[4]	0	no	yes	0	0 – 6	0 – 3	0	2	0	8
PM[5]	2	no	no	0	0 – 17	0 – 1	1	3	1	n/t

Notes

1. Scores for the Line Crossing and Letter Cancellation task are given as the collapsed numbers of cancelled elements on the left half and the right half of the stimulus sheets. All patients omitted all elements on the left half of both tests.
2. The scores on the Line Bisection test are the sums of scores for the three individual lines. All patients always placed marks that were far to the right of the true midpoint of the three lines.
3. CK was blind in his right eye, but had a complete visual field in his left eye, and showed no signs of extinction
4. JL was German but had lived in Scotland for over 50 years. JL's vocabulary was assessed with the vocabulary subtest of the revised version of the Wechsler Adult Intelligence Scale (WAIS-R). Her score was low, but she was tested by an inexperienced experimenter who did not ask the follow-up questions required to cue for the best answers. Otherwise, JL's communication skills and language use were very good.

5. PM had a history of chronic obstructive pulmonary disease (COPD) and a current MRSA (Methicillin-resistant Staphylococcus aureus) infection. His vocabulary was not assessed due to his breathing problems.

Control patients

A group of nine control patients with right-sided brain damage, but no (or only very mild) neglect took part in the experiment. They were recruited from the same hospital wards as the neglect patients. Demographic information of this control patients group is given in Table 10.3.

Table 10.3. Control patients. F = frontal; P = parietal; CN = caudate nucleus; LN = lentiform nucleus; BG = basal ganglia; IC = internal capsule; CB = cerebellum

	Sex	**Age**	**Educ.**	**Hand pref.**	**Onset - test**	**Lesion**
AG	M	78	10	R	94	R
NL	F	73	10	A	115	R F
SS	M	73	9	R	71	R FP
KO	F	79	9	R	123	R F + CN + LN
AW	F	79	14	R	16	R
LM	M	66	10	R	114	R F + IC + BG
SH	M	61	10	R	67	R BG
ID	M	76	14	R	51	R IC + LN
WC	M	75	12	R	192	R CB

A summary of the results of the diagnostic test battery is given in Table 10.4. The number of lines and letters crossed in the Line Crossing task and Letter Cancellation task were collapsed for left and right half. Scores on the Line Bisection task are given per line, with a '–' for marks to the left of the midpoint and a '+' for marks to the right of the midpoint.

Table 10.4. Results of control patients. A=anosognosia; VFD=visual field defects; E=extinction; PM=picture matching; LiCr=line crossing; LeCa=letter cancellation; LB=line bisection; D=drawing; PS=picture scanning; V=vocabulary, n/t=not tested

	A	**VFD**	**E**	**PM**	**LiCr**	**LeCa**	**LB**	**D**	**PS**	**V**
AG	0	no	no	3	18 – 18	16 – 17	0 ; 0 ; –3	2	10	34
NL	0	no	no	3	16 – 18	17 – 8	0 ; –2 ; +1	2	10	28
SS	0	no	no	3	18 – 17	11 – 17	–3 ; +2 ; +1	3	10	39
KO	0	no	no	3	17 – 18	20 – 18	–3 ; +3 ; +3	3	10	29
AW	0	no	no	3	18 – 18	20 – 20	–2 ; –2 ; +3	3	10	n/t [1]
LM	0	no	no	3	18 – 18	13 – 16	+1 ; +2 ; +2	3	10	52
SH	0	yes [2]	no	3	17 – 18	15 – 12	–3 ; +3 ; +2	2	8	15
ID	0	no	no	3	18 – 18	20 – 20	+3 ; +2 ; +3	3	10	59
WC	0	no	no	3	18 – 18	20 – 18	–3 ; –3 ; –1	3	10	38

Notes

1. AW was not tested on the vocabulary subtest because she was discharged from hospital before this part of the battery could be completed.
2. SH had hemianopia in the left lower quadrant of his visual field, but did not show any signs of extinction when stimuli were presented left and right of the vertical centre of his visual field.

A number of control patients had scores below the cut-off for perceptual neglect. In particular, AG scored below cut-off score on the Line Bisection task. NL, SS and LM scored below cut-off point on Line Bisection and Letter Cancellation. And SH scored below cut-off on the Line Cancellation task. However, all control patients achieved the maximum score on the Picture Matching task and Picture Scanning task (apart from SH, who scored 8/10 on the latter test). Therefore, if any mild neglect was at all present in any of the control patients, it was not severe enough to show up in the paradigm of the experiment.

Healthy elderly control participants

Finally, a group of 9 healthy elderly control participants took part in the experiment. They were recruited from the volunteer panel of the Department of Psychology of the University of Edinburgh. Demographic information of the healthy controls is given in Table 10.5. The group of healthy controls was tested only on the vocabulary subtest of the diagnostic test battery, results of which are included in the table.

Table 10.5. Demographic information of healthy control participants

	Sex	Age	Education (yrs)	Hand pref.	Vocabulary
ET	F	69	22	R	53
LG	F	71	15	R	64
JO	M	74	12	R	62
RC	F	68	16	R	56
AB	F	86	19	R	52
DN	M	60	19	L	63
JH	M	76	19	R	59
EM	F	74	10	R	56
DM	M	75	20	R	53

Both groups of control participants were matched as closely as possible to the neglect patients on the basis of age and education. A summary with the mean demographic information of all participants is given in Table 10.6.

Table 10.6. Mean Age and Education level (in years) of the three participant groups

Participants	Age	Educ.
Neglect patients	72.3	12.3
Control patients	73.3	10.6
Healthy controls	73.5	16.9

10.4 DESIGN AND PROCEDURE

Four different lists for the presentation order of the 40 trials were made, and lists were counterbalanced across participants. Presentation of the 20 pictures representing familiar and 20 representing unfamiliar proverbs was randomized within each list. A random design rather than a block design was used to avoid fatigue effects and a response bias within blocks. Another reason against employing a block design was that participants might get discouraged or confused when going through a long list of consecutive unfamiliar proverbs that they have never heard of. This was also one of the reasons for including 25% mirror versions of stimuli in the lists, so at least some trials 'made sense' from the perspective of a neglect patient, and encouraged completion of the experiment. The mirror versions furthermore acted as a control test to assess individual patients' ability to match the correct proverb with pictorial information they were aware of, and to avoid the possibility that participants learned that clues in the pictures were always on the left side. In each list, 10 pictures (5 familiar and 5 unfamiliar) were presented in mirror version, and the mirrored pictures were different ones in each of the four lists. Each stimulus was thus presented in mirror version once, in one of the lists. Presentation of normal and mirrored pictures within each list was randomized.

All patients (neglect and control) were first approached by the experimenter and were provided with information about the study. They received ample time to consider taking part and possibly discuss details with family or medical staff. Any formal testing did not commence before a patient had given informed consent to take part in the study. It was attempted to approach neglect patients as soon as possible after the stroke, or as soon as they were well enough to take part. Because testing typically took place while patients were still on the acute stroke ward or rehabilitation ward, test sessions had to be fitted in with other ongoing therapies and programmes on the ward, and usually took place in the morning. When patients were well enough to walk or sit in a wheel chair, a separate quiet test room on the ward was used, where they sat at a desk. In case the patient was not mobile, testing was carried out at the bedside with the curtains drawn around the bed. The healthy control participants were tested in a quiet test room in the Department of Psychology of the University of Edinburgh. For the patients, only one test session of not more than an hour was given on a day. In the first test session, subtests of the diagnostic battery were given. This test session took between 30 and 40 minutes. The proverb experiment itself was divided into two or more sessions (depending on the individual patients' abilities), which always took place on consecutive days.

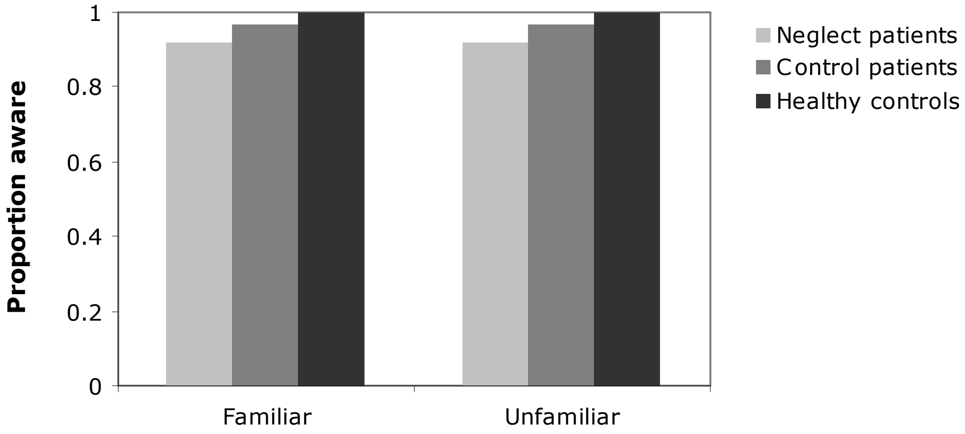
Pictorial stimuli in the experiment were placed on the table in front of the participant on their midline, or were held in front of the patient when testing was at the bedside. Presentation time was unlimited and participants always had the picture in full view while listening to the four proverbs. Proverbs were presented either on a portable CD player or on a laptop computer. Before hearing the proverbs, participants were instructed to examine each picture carefully, and to name all items that could be seen. They were told that with each picture they would hear four proverbs, and that they had to choose one that they thought matched best with the picture. They were told that some of the proverbs were very common ones, and that others might be less familiar. Patients were furthermore explained that in some cases the choice is very obvious, but that in other cases it might be less clear. In cases that they saw no relation of any of the proverbs to the picture, they were instructed to just guess any of the four, and that this did not matter to the experiment. Responses of participants were only valid when a complete proverb was repeated. When only one or two words, or a vague description was given, all four proverbs were repeated until the participant was able to repeat the complete proverb of their choice. After having made a response, patients were always asked what the reason for this choice was. When it was not obvious from this reason that they were aware of the target features in the picture, they were asked again to describe the picture to make sure that they were still unaware of left-sided items. Proverbs were repeated as often as requested by the participant, but this was rarely more often than twice. Before starting the first test session of the experiment, five practice trials were given, and before starting the second test session, three practice trials were given. After completion of the experiment a debriefing was given, explaining participants that this experiment tested their/patients' ability to process information from the left side of the pictures. They were shown that the clues to the correct proverb were always on the left side, and told that half of the proverbs used were translated Dutch proverbs.

10.5 RESULTS

Mirror trials

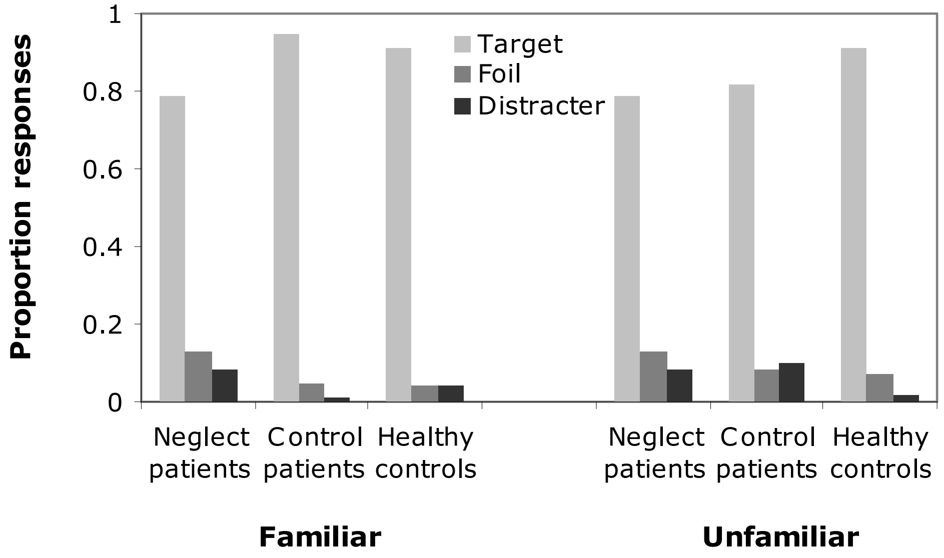
The mirror trials were analysed separately. Mean proportions of mirror trials on which participants were aware of the clues (in this case the right-sided features in the pictures) are shown in Figure 10.4.

Figure 10.4. Mean proportion of mirror trials on which participants were aware of the target features in pictures



Both the neglect patients and the two control groups were aware of the clues in almost all mirror trials. The mean proportions of responses on mirror trials on which participants were aware of the clues in the pictures are shown in Figure 10.5.

Figure 10.5. Mean proportion of responses on aware mirror trials of all participants



Chi-square tests (collapsed for familiar and unfamiliar trials) revealed that both neglect patients and the control groups performed significantly better than chance; for neglect patients, $\chi^2(2, N = 35) = 51.68$, $p < .001$, for control patients, $\chi^2(2, N = 83) = 158.43$, $p < .001$, and for healthy controls, $\chi^2(2, N = 90) = 210.15$, $p < .001$. This means that both neglect patients and the control participants selected the target proverb significantly more often than the foil and distracters. There was no difference in the proportion of target selections between neglect patients and the control groups, as tested with an ANOVA, $F(2) = 1.07$, $p = .36$. However, because there are large differences between patients' individual performances, these data were also analysed separately for the four patients. The results (collapsed for familiar and unfamiliar trials) are given in Table 10.7.

Table 10.7. Frequencies of responses on aware mirror trials of individual neglect patients

	Target	**Foil**	**Distracter**
CK	9	1	0
EW	7	0	0
JL	5	3	2
PM	6	1	1

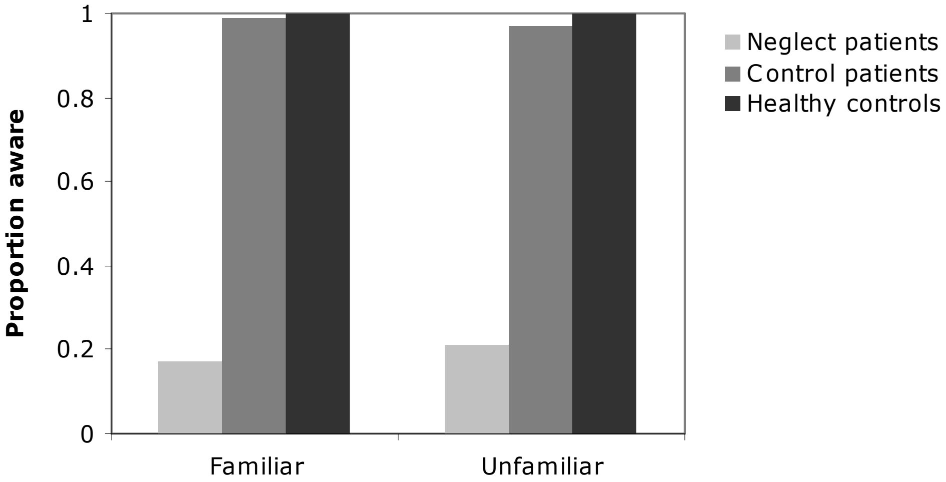
Chi-square tests were carried out on the distribution of responses of the four individual patients, revealing for CK, $\chi^2(2, N = 10) = 22.13$, $p < .001$, for EW, $\chi^2(2, N = 7) = 21.00$, $p < .001$, for JL, $\chi^2(2, N = 10) = 4.4$, $p > .10$, and for PM, $\chi^2(2, N = 8) = 10.75$, $p < .005$. Patients CK, EW and PM thus performed significantly better then chance; they all chose the target proverb significantly more often than the foil and distracter together. JL, however, performed at chance.

Experimental trials

Aware trials

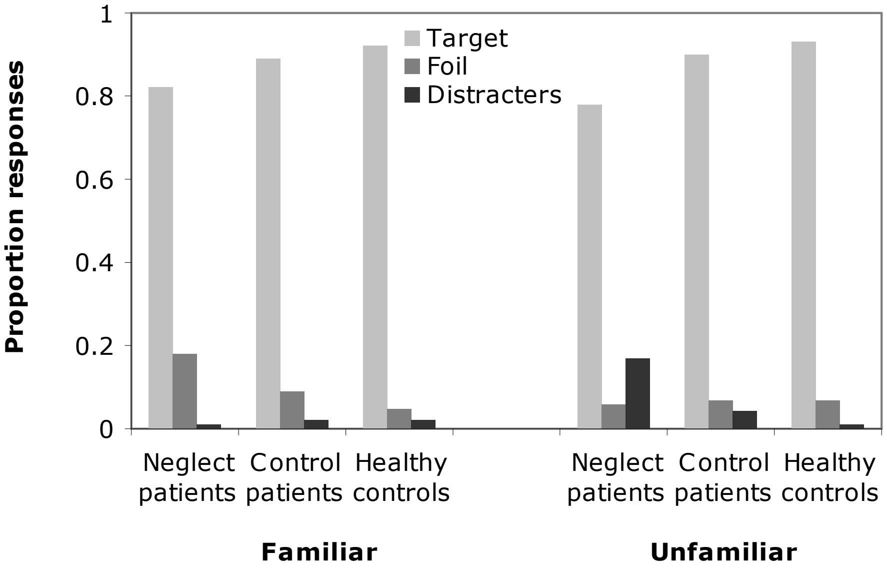
The experimental trials (with the target features in the left half of the pictures) on which participants were aware of the target features were analysed separately as well. Awareness of the target features in the pictures was assessed by asking the participant to describe everything they could see in the picture, both before and after they selected a proverb from the list. The mean proportions of experimental trials on which participants were aware of the target features are shown in Figure 10.6.

Figure 10.6. Proportion of experimental trials on which participants were aware



The healthy controls were always aware of the left-sided target features in the pictures. In case of the control patient group, only one patient was unaware of the target features in a number of trials. Neglect patients were aware of the left-sided elements on average in only 17% and 21% in familiar and unfamiliar trials. The mean proportions of responses on these ‘aware trials’ for the three participant groups are given in Figure 10.7.

Figure 10.7. Proportion of responses of all participants on aware trials



Again, both neglect patients and control participants performed well when they were aware of the crucial left-sided elements in the pictures, even when these were on the left side. The proportions of target, foil and distracter responses of neglect patients were tested with a chi-square test, revealing that the distribution of their responses as a group was significantly different from chance for familiar trials, $\chi^2(2, N = 10) = 17.2$, $p < .001$, and for unfamiliar trials, $\chi^2(2, N = 11) = 18.99$, $p < .001$. This was also true for the control patient group for familiar, $\chi^2(2, N = 124) = 264.06$, $p < .001$, and for unfamiliar trials, $\chi^2(2, N = 124) = 269.81$, $p < .001$, as well as for the healthy elderly control participants, on both familiar, $\chi^2(2, N = 150) = 310.95$, $p < .001$, and on unfamiliar trials, $\chi^2(2, N = 150) = 298.68$, $p < .001$. All participants thus selected the target proverb more often than the foil and distracter proverbs for both familiar and unfamiliar proverbs.

Two (familiar versus unfamiliar) by 3 (target, foil, distracter) chi-square tests revealed no differences in performance between familiar and unfamiliar aware trials for the neglect patients, $\chi^2(2, N = 21) = 1.36$, $p > .25$, nor for control patients, $\chi^2(2, N = 248) = 0.32$, $p > .25$, nor for healthy controls, $\chi^2(2, N = 300) = 1.01$, $p > .25$. The proportion of target responses was also compared between the three types of participants directly with a between-subjects ANOVA, revealing no significant difference for familiar trails, $F(2) = 1.22$, $p = .32$, and no significant difference for unfamiliar trials, $F(2) = 1.87$, $p = .18$.

The responses of individual neglect patients were also investigated, as there are large differences in the proportion of trials on which they were aware, as well as in their responses. Data are given in Table 10.8.

Table 10.8. Frequency of responses of individual neglect patients on aware trials

	Familiar			**Unfamiliar**		
	Target	*Foil*	*Distr.*	*Target*	*Foil*	*Distr.*
CK	4	1	0	5	1	0
EW	2	1	0	3	0	0
JL	0	0	0	0	0	0
PM	2	0	0	1	0	1

The number of data points is too small to analyse this statistically, but CK, EW and PM all seemed to select the target proverb in most of the trials in which they were aware of the left-sided target features. JL was never aware of any of the target features in the pictures.

Unaware trials

The crucial trials in this experiment were those in which neglect patients were *not* aware of the target features in the pictures. The frequencies of target, foil and distracter responses of neglect patients on these ‘unaware trials’ are given in Table 10.9.

Table 10.9. Frequency of responses of neglect patients on unaware trials

	Familiar			**Unfamiliar**		
	Target	*Foil*	*Distr.*	*Target*	*Foil*	*Distr.*
CK	6	2	2	3	3	3
EW	1	2	7	3	1	3
JL	4	4	6	2	6	7
PM	5	2	6	1	6	6

Chi-square tests were calculated with foil and distracter responses collapsed and Yates' correction applied. These revealed that CK's performance was significantly different from chance performance for familiar trials, χ^2(Yates', 1, N = 10) = 4.8, $p < .05$, but not for unfamiliar trials, χ^2(Yates', 1, N = 9) = 0.04, $p > .25$. CK selected the target proverb significantly more often than the foil and distracters together in familiar trials, but selected the target equally often as the foils and distracters in unfamiliar trials.

None of the distributions of the other three patients differed significantly from chance level. For EW, for familiar trials, χ^2(Yates', 1, N = 10) = 0.93, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 7) = 0.43, $p > .25$. For JL, for familiar trials, χ^2(Yates', 1, N = 14) = 0.0, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 15) = 0.56, $p > .25$. And for PM, for familiar trials, χ^2(Yates', 1, N = 13) = 0.64, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 13) = 1.25, $p > .25$. Therefore, these three patients always performed at chance when they were not aware of the target features in the pictures.

CK's performance on these unaware trials was also compared directly to his performance on trials on which he was aware. Two (aware versus unaware trials) x 3 (target, foil, distracter) chi-square tests revealed that the distribution of CK's responses over the three proverb categories was the same for aware and unaware *familiar* trials, χ^2(2, N = 15) = 2.12, $p > .13$ (1-tailed), but was (marginally) different for aware and unaware *unfamiliar* trials, χ^2(2, N = 15) = 4.07, $p > .05$ (1-tailed). These results suggest that for familiar trials, CK performed equally well on trials on which he was unaware of the clues in the pictures, as on trials on which he was aware; in both cases he selected the target proverb more often than foil and distracters. For unfamiliar trials, however, he selected the target more often than foil and distracters when he was aware of the clues, but performed at chance when he was not aware of the clues, and this difference in performance between aware and unaware unfamiliar trials was significant. Overall, there is thus evidence that CK has processed left-sided information from the pictures implicitly for familiar proverbs, but not for unfamiliar proverbs.

Stricter criterion of unawareness

As mentioned above, awareness of neglect patients for the target features in the pictures was assessed by asking them to describe the picture not only *before* selecting a proverb, but also *afterwards*, as an extra control measure for awareness. In the literature, studies that have employed a similar paradigm of presenting patients with visual stimuli on the basis of which they had to make decisions (e.g. studies that employed a burning house paradigm or chimeric pictures, see Section 9.2) have never used this extra control measure. The above analysis of unaware trials was based on those trials on which the patient did not indicate awareness of target features before selecting a proverb. There were a number of trials, however, on which patients were not aware of the target features before selecting a proverb, but when asked to describe the picture after a response was made, they appeared able to detect the target features. It could be argued that in these trials, the patient had become aware of the target features while listening to the proverbs, or while thinking about the response. In these cases, the response would thus have been made on the basis of *explicit* processing of the pictures. A separate analysis was carried out, omitting these latter trials from the analysis, and thus employing a stricter criterion of unawareness; only trials on which patients were unaware of the target features both before and after having selected a proverb were analysed. Data are given in Table 10.10.

Table 10.10. Frequency of responses of neglect patients on unaware trials, using a stricter criterion of unawareness

	Familiar			**Unfamiliar**		
	Target	*Foil*	*Distr.*	*Target*	*Foil*	*Distr.*
CK	1	1	2	1	1	3
EW	1	1	7	3	1	3
JL	4	4	6	2	6	7
PM	3	1	6	1	6	6

Again, chi-square tests were calculated, with foil and distracter responses collapsed and Yates' correction applied. None of the distributions differed significantly from chance. For CK, for familiar trials, χ^2(Yates', 1, N = 4) = 0.33, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 5) = 0.07, $p > .25$. For EW, for familiar trials, χ^2(Yates', 1, N = 9) = 0.33, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 7) = 0.43, $p > .25$. For JL, for familiar trials, χ^2(Yates', 1, N = 14) = 0.0, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 15) = 0.56, $p > .25$. And for PM, for familiar trials, χ^2(Yates', 1, N = 10) = 0.0, $p > .25$, and for unfamiliar trials, χ^2(Yates', 1, N = 13) = 1.25, $p > .25$. With this stricter criterion of unawareness employed, none of the patients thus showed any signs of implicit processing.

Effect of reading out proverbs

Due to a failing CD player, all proverbs in the second experimental session of CK were read out by the experimenter. Therefore, CK's responses in the first and second session were compared to investigate whether there was any effect of reading out rather than playing back the proverbs. Data are given in Table 10.11.

Table 10.11. CK's responses in the first and second experimental session. T = target; F = foil; D = distracters

	Familiar			**Unfamiliar**		
	T	*F*	*D*	*T*	*F*	*D*
First session	3	2	2	1	3	2
Second session	3	0	0	2	0	1

There were too few data points to analyse this statistically, but when looking at the frequencies, there are no large differences in performance between the two test sessions. It is therefore unlikely that CK has selected the target proverb more often in the second session because he might have picked up an unintentional emphasis or change in pitch or tone of the experimenters voice when reading out the target proverbs.

Relationship of implicit processing with other variables

Only one of the four patients showed evidence of implicit processing. To explore whether the ability of neglect patients to process stimuli implicitly was related to their severity of neglect, regression analyses of their implicit processing performance and scores from the diagnostic tests were calculated. The measure for implicit processing was taken as the proportion of target responses on trials on which they were not initially aware of the target features in the pictures. Variables that were tested are given in Table 10.12. Performance on the Line Crossing task was taken as the number of lines crossed out in total (all patients only crossed out lines on the right half), and performance on the Letter Cancellation test as the total number of letters cancelled (all patients, again, only cancelled letters on the right). The scores for the Picture Scanning task and Line Bisection task were taken as they have been scored initially. For all patients, also a 'basic matching performance' score was calculated, which was the percentage of correct responses on all trials on which they were aware of the crucial elements in the pictures, including mirror trials.

Table 10.12. Variables that may be related to patients' ability of implicit processing. IP = implicit processing performance, BM = basic matching performance, PS = picture scanning, LiCr = line crossing, LeCa = letter cancellation, LB = line bisection

	IP	**BM**	**PS**	**LiCr**	**LeCa**	**LB**
CK	0.47	0.86	3	13	15	2
EW	0.28	0.92	4	11	6	0
JL	0.21	0.50	0	6	3	0
PM	0.21	0.75	0	17	1	1

Regression coefficients were calculated for each of these variables with the implicit processing performance of patients. None of the other variables significantly predicted implicit processing performance (with all $p > .05$), except for the Letter Cancellation task performance: $\beta = .99$, $t(4) = 10.15$, $p = .01$. The Letter Cancellation task is generally regarded as a good clinical tool to detect perceptual neglect, and is a sensitive measure for the severity of neglect (e.g. Ferber & Karnath, 2001). Letter Cancellation performance was positively correlated (and hence neglect severity was negatively correlated) with patients' ability to process material implicitly in this experiment.

Anecdotal evidence for implicit processing

On a number of occasions, patients' comments during the experimental trials suggested that they might have processed neglected information implicitly. For example, CK correctly matched the target proverb ("The chickens have come home to roost") with a picture in which on the left half some chickens entered a barn, which was an open garage on the right half, with a car coming out (see Appendix G for images of all experimental stimuli). CK did not report the barn or the chickens before selecting a proverb. However, when asked for the reason of his choice, he responded: "I thought I saw feathers here", while pointing to the far right side of the picture. This suggests he might have processed the chickens on the left implicitly. On another occasion, patient JL reported seeing "A man with a red tie", when looking at a picture in which a man (without tie) was holding a red heart in his (right) hand on the left side of the picture. When the experimenter asked where she could see a red tie, JL was surprised and said: "Oh I don't know where that came from". This suggests that she might have processed the 'red object' implicitly, and initially misinterpreted this as a red tie. Also one of the control patients, SH, showed some indication of implicit processing in one of the two trials on which he was not aware of the left-sided elements in the picture. SH looked at a picture, which represented the proverb "One bird in the hand is worth two in the bush", on which a man held a bird in his right hand, and to his right was a bush with two birds in it. SH had not reported any of these items, and when he had heard the proverbs, he initially did not give a response. When eventually urged to choose a proverb, he said: "I am thinking about 'one bird in the hand'", but still seemed to be confused. When asked why he was thinking about this proverb, WM said "Because the man *might* have a bird in the hand". He then looked at the picture again for a long time and eventually selected this proverb, but still without becoming consciously aware of any of the target features in the picture. The fact that SH seemed so confused and perhaps kept searching for clues that might have confirmed his strong thought about the target proverb, suggests that he might have processed some information from the left of the picture implicitly. A final suggestion of the presence of implicit processing comes from patient JL. On eight trials, she gave as reason for her choice: "I don't know, I can't see a …", mentioning a key word of one of the proverbs. In 5 of these 8 trials this concerned the target proverb, which she eventually also selected in 3 of these 5 cases. In one case, she eventually did not select the target proverb, maintaining that “it is not that one”, but also refusing to select any other proverb. In the fifth trial in which she referred to a key word from the target proverb, she selected the foil, which shared the key word she mentioned with the target. In the 3 remaining trials of the 8, JL referred to a key word in one of the distracter proverbs and also selected these. The fact that on five trials, JL did not report the left-sided target features in the pictures but seemed to be confused when not being able to see these specific elements after hearing the proverbs, suggests that she might have processed this information implicitly.

10.6 DISCUSSION

Evidence for implicit processing

The predictions for this experiment, on the basis of the assumptions of the unitary and workspace models, were that (1) for familiar proverbs, neglect patients who are not aware of the crucial features in the pictures might still select the target proverb more often than the foil, and (2) for unfamiliar proverbs, they would select the target and foil equally often. The results of patient CK confirm these predictions. These results are very difficult to explain by the gateway model. When CK was not aware of the left-sided target features in the pictures, he still selected the target proverb significantly more often than the foil and distracter proverbs in familiar trials. This was not the case for unfamiliar trials, in which he performed at chance level, selecting each of the proverb types equally often. Furthermore, CK’s performance on familiar trials on which he was *not* aware of the target features did not differ from his performance on familiar trials on which he *was* aware of them. On unfamiliar trials, however, he performed significantly better when he had overtly reported the target features in pictures before selecting a proverb than when he had not.

CK’s above chance performance on familiar unaware trials could not be attributed to clues being present in the right halves of the pictures, and neither could the difference between his performance on familiar and unfamiliar unaware trials be attributed to a difference in difficulty between these trials. These possibilities have been explored in the pilot experiments for the pictures as well as by testing two control participant groups, and by including mirror versions of the pictures in the test sessions. The pilot participants were presented with only one half of the pictures. When they were presented with the left halves, they selected the target proverb in virtually all trials. However, when they saw only the right halves, they performed at chance, selecting the target as often as the foil and distracters. The fact that CK performed above chance when he only reported elements from the right halves of pictures, suggests that he had available additional information about the left halves of pictures implicitly. Additionally, the performance of control patients and healthy controls in the experiment did not differ between familiar and unfamiliar proverbs, and CK's performance on the mirror trials was equally high for familiar and for unfamiliar trials, confirming that there was no difference in difficulty or clarity between the two conditions. The difference between CK's performance on familiar and on unfamiliar trials could thus be taken to reflect the difference in semantic content of the pictures in the two conditions. The fact that CK demonstrated the ability of implicit processing only in case of familiar proverbs, suggests that only when pre-existing wide networks of representations in LTM could be activated by neglected perceptual information, did this lead to further processing, sufficient to influence behavioural responses. The presence alone of target features in the pictures, related to key words in the target (and foil) proverbs, did not appear sufficient to influence behaviour. This experiment replicated the findings of the study cited by Logie and Della Sala (2004). In this study, neglect patient GSt selected the correct proverb in 8 (out of 20 trials) for familiar proverbs, and in 4 (out of 20) trials for unfamiliar proverbs. His performance was above chance on familiar trials (as tested with a 1-tailed binomial test, $p < .02$), but not on unfamiliar trials ($p = .44$).

One important caveat in this experiment is that the above findings are based on analysis of CK's performance according to a loose criterion of unawareness that has always been employed in the literature; the analysis was based on all trials on which CK did not report any of the target features in the pictures before selecting a proverb from the list. In these trials, CK also motivated his responses by giving reasons that did not indicate awareness of the target features. His reasons were either 'non-specific' reasons, such as "It is a guess", "I don't know", or "It just seems to be the right one", or they were 'specific' reasons, such as references to irrelevant aspects from one of the proverbs in the list. However, in 10 out of the 19 trials on which CK was unaware of the target features *before* selecting a proverb, he appeared to be aware of the target features *after* having made and motivated a response, when asked to describe the picture again. It could be possible that, in these 10 trials, CK had become aware of the target features to some extent, perhaps while listening to the proverbs or when deciding which proverb to select. The explicit information from the left side of the pictures could then have been sufficient to support proverb selection, but not sufficient for him to motivate the reasons for his choice. Upon the request from the experimenter to describe the picture again, the information could have been processed further into awareness, allowing CK to overtly report the target features. The literature does indeed support the idea that there seems to be a gradient of awareness for visual information. Information can be explicitly available to a certain extent, sufficient to support some forms of decision making, but insufficient to give the perceiver confidence to report the information overtly (e.g. Hannula et al., 2005; Reingold & Merikle, 1990; Verfaellie et al., 1995).

It is clear that interpreting CK's performance on these 'post-awareness' trials is very difficult and tricky. In the present experimental paradigm it is impossible to assess exactly when a patient was or became aware of certain information in the pictorial stimuli. CK could have become aware of the clues in the pictures only after he had made a response, perhaps cued by the request to describe the picture again. However, it is equally possible that CK became aware of the target features in the pictures when (or even before) listening to the proverbs, in which case he made his responses on the basis of (partially) explicit information. The fact that CK selected the target proverb in 7 of the 10 trials on which he appeared aware of the clues after having made a response, would support this latter option. His performance on these post-awareness trials appears to be better than on trials on which he never gained awareness of the left-sided target features. The claim that CK has demonstrated implicit semantic processing would not be justified, if this were the case. The consequences of this possibility are discussed further in the General Discussion (see Section 11.2.4).

Individual patients' ability of implicit processing

The results of the present experiment, as well as the reviewed literature (see Section 9.2), suggest that not every neglect patient appears to be able to process visual stimuli implicitly. Only one out of four patients showed some implicit processing of information from the pictures (when the 'normal' loose criterion of unawareness was used), and similarly, in many studies only a small subgroup of tested patients processed material implicitly. Severity of neglect is likely to affect the ability of implicit processing. A patient with very mild neglect would not be expected to process much information implicitly, because left-sided information could still be processed explicitly to a large extent. On the other hand, a patient with very severe neglect might not be able to process any left-sided information, because the severe attention deficit could prevent explicit and implicit perception of left-sided visual information. The results of Peru et al. (1996) support this hypothesis. They compared performance of two patients with very mild, two patients with moderate, and two patients with severe neglect on different tasks. Only the two patients with moderate neglect showed signs of implicit processing (Peru et al., 1996). Results of the study by Verfaellie et al. (1995) also imply a relationship between the severity of neglect and the ability of implicit processing. In their experiment, they distinguished two groups of patients. One group of patients had very poor identification performance of left-sided stimuli on bilateral presentations, but their same/different judgments were above chance. The other group performed above chance for identification of left-sided stimuli, and their same/different judgement performance did not exceed this identification performance. The first group of patients thus had relatively severe neglect and showed implicit processing, whereas the second group showed mild neglect and no implicit processing. The relationship of neglect severity with the ability of implicit processing might also account for the fact that in the present experiment, only one out of four patients showed implicit processing of the visual stimuli. The neglect symptoms of the other 3 patients might have been too severe to process any visual information, either explicitly or implicitly. This hypothesis is consistent with the significant positive correlation between patients' implicit processing performance and their performance on a sensitive diagnostic test for neglect (letter cancellation): CK showed severe neglect, but still performed much better on this test than the other three patients. Of the 20 target letters on the right side he omitted only 5, whereas he omitted all 20 stimuli on the left half. This is far below cut-off score (32) for this test. Patients EW, JL and PM only crossed out 6, 3 and 1 letter on the far right of the stimulus sheet, respectively. CK furthermore performed better than the other three patients on the line bisection task and the drawing from memory task, but these differences were not significant.

The ability to process visual material implicitly has also been associated with the extent and location of the brain lesion. As discussed in Section 9.3, lesions that affect visual and/or temporal cortices might prevent any visual processing. There is no evidence that these specific areas were affected in any of the four patients in the present experiment. CK's stroke affected his right fronto-temporal lobe. EW had a large right Cerebral Vascular Accident (CVA), which might have affected his temporal lobe, but no details about the specific location of the lesion are available. JL had a small focal stroke in the inferior posterior parietal cortex, the key area associated with neglect. And finally, PM had a right Total Anterior Circulation Stroke (TACS), again without much detail available as to the precise location of the stroke. There is too few details available (from too few patients) about the lesion sites to say anything about the relationship of lesion and ability of implicit processing. The data cannot explain the absence of implicit processing in EW, JL and PM, nor the presence of it in CK (whose temporal lobe was affected, but still showed implicit processing).

There are no other apparent differences between patient CK and the other three patients that could explain why only CK did show evidence of implicit processing. The fact that CK was blind in his right eye is unlikely to have influenced his performance. Neglect is primarily an attention deficit, and symptoms can manifest itself in the visual field of only one eye. The visual field of CK's left eye was completely intact. One difference between CK and the other three patients was that CK was left-handed, whereas the others were right-handed. It has been found, however, that the right hemisphere is predominantly specialised for hemi-inattention even in non-right handed patients. In a large screening study, Ringman, Saver, Woolson, and Adams (2005) found that among 45 left-handed or ambidextrous patients a right hemisphere predominance of lesions producing moderate or severe neglect was found that did not differ from that among right-handed patients. CK was 78 year old; the same age as JL. Patients EW and PM were both younger (72 and 61 years old, respectively). Age is thus unlikely to have influenced the ability to process visual material implicitly. Consistent with this, Park et al. (2006) have found that age did not influence the incidence or severity of neglect. In case of CK, the proverbs were read out by the experimenter due to a failing CD player in the second (of the two) session. An unintentional emphasis of the experimenter when reading out the target proverbs may have led to the above chance performance of CK. However, there did not seem to be a difference in performance of CK between the first and second session. Also, if CK's above chance performance was due to him picking up a change in the experimenters voice, no difference between familiar and unfamiliar proverbs would have been expected. Therefore, this is an unlikely explanation of the above chance performance of CK.

Experimental paradigm

One other possible reason for why three patients did not show any implicit processing in the present experiment, is that the paradigm that was used may have been too insensitive. Specifically, the measure for implicit processing used (i.e. the above chance multiple-choice matching of pictorial information with lexical information) might have been too insensitive. The patients' task is a relatively complex, cognitively demanding task. Any material that is perceived implicitly must undergo further elaborate processing in order to exert an influence on patients' performance in this task. Visual information from the pictures must be processed to a semantic level of representation of the objects, and further to activation of the global representations of proverbs. These representations have to be kept in mind while listening to four proverbs. This auditorily presented lexical information must then be encoded as well and compared to the activated proverb representations, and a match has to be made. The task was thus quite complex, and the measure for implicit processing employed here might have been too crude to pick up any implicit processing of visual material that might have taken place. This notion seems to be supported by the literature. Reliable implicit processing has been demonstrated especially in studies employing simpler tasks, in which any implicitly perceived visual material did not need to be processed to such an elaborate degree, such as a same/different judgment paradigm (e.g. Berti et al., 1992; Farah et al., 1991; Verfaellie et al., 1995). Moreover, the present task might have been too difficult at least for patient JL; her performance in general was relatively poor. On the mirror trials, on which she was always aware of the crucial elements, she performed only marginally significantly better than chance; she selected the target proverb in only half of these trials. If the task itself was indeed too difficult for JL, any implicit processing would also have been less likely to take place, as this requires the same basic cognitive processing as conscious processing. Additionally, for implicitly processed information to affect behaviour of a patient, this patient must be willing to make decisions on the basis of information that they are not aware of (i.e. make guesses), and be motivated to continue a demanding task that does not make any sense from their point of view. For instance, testing patient NC (whose data are not discussed in this thesis) could not be finished because he refused to make guesses. His neglect was very severe and in each trial he indicated that he could not associate any information from the picture to any of the proverbs. The proverb matching task might thus have been too difficult, and the measure for implicit processing too crude to demonstrate any implicit processing in thee of the patients tested in this experiment.

An additional issue with the paradigm used in this experiment is related to the presence of conscious processing of the stimuli. It has been argued that unconscious perception is very weak, and that conscious perceptual influences typically override unconscious ones when both are present. Unconscious perceptual effects may be obtained most reliably only when conscious perception is completely absent (e.g. Snodgrass, Bernat, & Shevrin, 2004). In this experiment, there is much information that patients perceived consciously from the pictures, and this information might have driven the responses, even if there was also some information perceived unconsciously. Support for this hypothesis comes from the observation that the neglect patients very often tried to match any of the proverbs they heard, to any of the information from the pictures that they were aware of. Patients might have felt more confident in selecting a proverb when they could base this on anything they consciously perceived in the pictures (even when these reasons were sometimes very farfetched or bizarre), rather than making complete guesses, which would be their subjective experience of making a choice based on implicit information. An experimental design in which conscious perception cannot influence behaviour to such a degree, might be more sensitive in measuring implicit perception. This is, for example, the case in studies that have employed a semantic priming paradigm, in which stimuli were presented very briefly (e.g. Làdavas et al., 1993; McGlinchey-Berroth et al., 1993; 1996; Kanne, 2002). In these experiments, patients did not have the stimuli in full view while making a decision.

Familiarity with proverbs

Even though the familiarity of all proverbs was piloted extensively, there was no reliable assessment of participants' individual knowledge of the British proverbs. The healthy elderly volunteers in the pilot study rated all British proverbs to be highly familiar, and all foreign proverbs to be very unfamiliar. However, knowledge of proverbs may vary considerably across individuals, for example due to differences in general intelligence, or educational background. Patients who might have had a very limited knowledge of British proverbs, would not be expected to perform much better for the familiar (British) proverbs than for the unfamiliar proverbs. The neglect and control patient groups did have a smaller number of years of education than the healthy control group. Therefore, the actual familiarity of participants with British proverbs might have differed between groups, and differentially influenced performance on the task. Nonetheless, the fact that CK did show some evidence for implicit processing of familiar proverbs, and the other three patients did not, does not seem to be related to educational background. CK had 12 years of education, whereas EW, JL and PM had 14, 12 and 11 years respectively. Additionally, CK did not seem to score higher than the other patients on the vocabulary test (which is an indicator of verbal intelligence). In contrary, CK scored only 27 out of a possible 66, and EW scored 45 (comparative data for this test for JL and PM were not available). A good way of investigating whether familiarity with the proverbs had an effect on participants' performance would be to carry out a control study with Dutch neglect patients. In this case, the advantage of familiarity for implicit processing should be with the Dutch proverbs, and the British proverbs will be the unfamiliar proverbs. The specific predictions would thus be reversed for the two proverb categories. Also, a questionnaire after the experiment, in which patients are asked about the meaning of some of the familiar proverbs, could have addressed this issue.

Conclusion

The main finding in the present experiment was the demonstration of implicit semantic processing in a neglect patient, consistent with the predictions of the workspace and unitary models. These results were found when a measure of unawareness was used that has also been the default measure of unawareness in previous studies with similar paradigms. Patient CK consistently selected the correct proverb from a list of four on the basis of visual information from pictures that he did not report overtly. This was the case only for familiar British proverbs; for unfamiliar foreign proverbs he performed at chance level. These data are consistent with the hypothesis that implicit processing reflects the activation of LTM representations by perceptual information, in the absence of the generation of a conscious visual representation of the perceptual information in working memory (or the focus of attention). The gateway model has difficulty interpreting these data and could only account for the results if extra pathways are added to the model, making it less parsimonious.

A second main finding of this experiment was that when a more strict measure of unawareness was employed than is usually the case in the literature, the above chance performance of CK on familiar trials disappeared. This has consequences for the way the results of the present experiment, as well as the results of previous experiments using similar paradigms, should be interpreted. It is possible that the results reflect (degraded) aware processing, rather than implicit processing of the stimuli.

CHAPTER 11

General Discussion

In the first two sections of the present chapter, the main findings from the seven cognitive psychology dual-task experiments (Chapters 2 – 8) and the neuropsychology experiment (Chapter 10) will be discussed, and converging findings from these two approaches will be emphasised. In the third section, some wider theoretical implications of the results will be discussed. Directions for future research will be included throughout, in the relevant sections. The chapter will finish with stating the main conclusions that can be drawn from the research described in this thesis.

11.1 EXPERIMENTS 1 – 7

The main aim of the seven dual-task experiments was to compare the three types of models of the interaction between WM and LTM, by testing their specific predictions about the effects of irrelevant visual input on different visual WM tasks. Two important main findings emerged from the experiments, namely (1) visual short-term retention is relatively insensitive to disruption by irrelevant visual input, whereas (2) visual imagery is susceptible to interference by irrelevant visual input. This pattern of findings is most consistent with the predictions of the workspace model. The present section will discuss these findings and the theoretical interpretation in terms of the three models in more detail.

11.1.1 Interference with short-term retention

In the workspace model, working memory is assumed to be a mental workspace that is functionally separate from, and deals with the activated contents from LTM. Visual images are thought to be maintained in the workspace independently of the perceptually driven activation of LTM. The hallmark of the gateway model is that all perceptual input has direct access to the WM system, before activating representations in the long-term knowledge base. In this view, any perceptual input should disrupt maintenance of material in WM considerably. The unitary model is based on the assumption that short-term and long-term memory processes reflect the operation of a single unitary system, and views working memory as the activated subset of LTM representations (e.g. Cowan, 1988; 1995; 2005). In this view, a short-term retention task would involve the temporary maintained activation of LTM representations, whereas perceptual input also activates LTM. Cowan (1988, 2005, Cowan et al., 2007) proposes a central executive which is responsible for the activation of information from LTM, and for short-term retention through the continued activation of LTM items in the focus of attention. The functions of the central executive are regarded as cognitively effortful processes, and the focus of attention as capacity limited. It follows from these assumptions that a perceptual task should interfere with a retention task. Therefore, both the gateway and unitary model would predict disruption of visual short-term retention from irrelevant visual input, whereas the workspace model predicted no disruption.

In Experiment 1 it was demonstrated that a visual short-term retention task (the visual patterns task) was disrupted significantly by a visual perception task (picture naming). These results as such are inconsistent with the workspace model. However, the results of Experiment 1 in combination with the results of Experiment 3 do provide some evidence for the workspace model, as this model is better able to (predict and) account for these combined results than the gateway and unitary model. In Experiment 3, a task involving visual WM (the letter imaging task) was demonstrated to significantly disrupt recall on the visual patterns task, and significantly more so than the picture naming task did. The letter imaging task was very similar to the picture naming task in that both involved the activation of LTM by a series of stimuli to which participants had to give a speeded response. Both tasks could thus be argued to be equally attention demanding. One important difference between the tasks is that the picture naming task did not place a high demand on visual WM (there was no requirement to further process or remember the pictures), whereas the letter imaging task involved holding the images in visual WM on a temporary basis while responding to the specific question about their visual appearance. The differentiating effects of these two interference tasks on visual short-term retention could thus be explained in terms of their demand on visual WM. This interpretation is consistent with the workspace model. It is more difficult to explain the differentiating effects in terms of demand on attentional resources, as the unitary model would do, due to the similarity of the two tasks. The data do not rule out the possibility that picture naming and letter imaging *did* somehow differ in their attentional demand, but the unitary model could not make clear predictions about this, and could only interpret the data post hoc at best. Also the gateway model did not make clear predictions about the different effects of the two secondary tasks, and has more difficulty explaining the larger disruptive effect of letter imaging. This model would predict, if anything, less disruption of the visual patterns task by letter imaging than by picture naming, given that letter imaging involves no visual perceptual input. The combined results of Experiments 1 and 3 are thus best predicted and accommodated by the workspace model.

Clearer support for the prediction of the workspace model that visual short-term retention would be unaffected by irrelevant visual input comes from Experiments 4 – 6. In these experiments an insensitivity of the letter retention task to disruption by both DVN and irrelevant pictures was demonstrated. These results especially contradict the predictions of the gateway model, according to which any perceptual input should have substantial impact on a WM retention task. The unitary model is able to account for the results of Experiments 4 and 5 by assuming that the interference tasks were not very attention demanding. It could be argued that executive processes were able to maintain the letters of the retention task activated in the focus of attention, and that the perceptual input was prevented from entering the focus. However, this explanation runs into difficulty when trying to account for the double dissociation of interference effects between Experiments 5 and 6 (this argument will be elaborated on in the next section). The combined results of Experiments 4, 5 and 6 are thus, again, accommodated best by the workspace model.

A lack of effect of irrelevant perceptual input on visual short-term retention, as found in Experiments 4 – 6, can also be found in the literature. Andrade et al. (2002) showed that DVN had no effect on the short-term retention of visual patterns or unfamiliar Chinese characters. Both Avons and Sestieri (2005) and Zimmer and Speiser (2002) replicated this lack of interference of DVN on short-term memory for patterns. Furthermore, Quinn and McConnell (2006) and Zimmer and Speiser (2002) demonstrated that DVN does not disrupt the retention phase of the pegword mnemonic. Even though the pegword mnemonic is commonly regarded as a visual imagery task, its retention phase may well involve passive storage in long-term memory rather than in working memory given that peg word images are complex, have a rich semantic content, and typically involve sequences of items that exceed the normal assumed capacity of working memory. Indeed, the peg word mnemonic is widely used as a means to boost memory performance by adding rich semantic content to the representations of each item. Only the encoding and retrieval phases of this task rely on the generation (encoding) or re-generation (retrieval) of images on the basis of representations from LTM, and this offers an account for the observation that only the encoding and retrieval phases are susceptible to interference from perceptual input.

The results of Experiment 1 are inconsistent with the findings reported by Quinn and McConnell (2006) and Zimmer and Speiser (2002). However, pattern memory has very different cognitive requirements from the peg word mnemonic, and in particular is likely to have minimal semantic content. Therefore, we would not expect pattern memory and the peg word mnemonic to show the same pattern of sensitivity. One possible reason why pattern memory was disrupted by perceptual input is that there was an increase in general processing load associated with the dual task requirements. Participants did not just view and ignore the perceptual stimuli, as they did, for example, in Experiments 4 and 5, but they engaged in a difficult attention-demanding picture naming task. The increased load on attentional and executive components for coordination in the dual-task condition might have led to the drop in performance in both tasks (e.g. Duff & Logie, 2001; Logie, Zucco & Baddeley, 1990). This interpretation is consistent with both the workspace and the unitary model. However, as argued above, the unitary model has more difficulty explaining the results of Experiment 1 and 3 together, whereas the workspace model could account for these combined results more readily.

Inconsistent findings

Effect of irrelevant visual input

One caveat is that there are also a number of inconsistent findings in literature, of studies that have found a detrimental effect of irrelevant visual input on visual short-term memory tasks. This inconsistency in the findings emphasises the importance of a coherent theoretical interpretation of interference with visual working memory, and of the necessity of future research to investigate what aspects of visual working memory are susceptible to interference by which types of irrelevant visual input exactly. In the light of the repeatedly demonstrated absence of substantial impact of irrelevant visual input on short-term memory for visual patterns in the previous literature (Andrade et al., 2002; Avons & Sestieri, 2005; Zimmer and Speiser, 2002), the relatively large effect of irrelevant pictures on pattern memory demonstrated by Della Sala et al. (1999) seems peculiar. The effect size they found is also much larger than the effect found in Experiment 1. Della Sala et al. measured recall performance of patterns in terms of the memory span, calculated as the mean number of cells reproduced in the last three patterns correctly recalled. Memory span in the control condition was 10.9 (SD = 1.13), and in the irrelevant picture condition 7.1 (SD = 1.15). The drop in performance as a percentage of the control performance was thus 34.9%, compared to a drop of only 9.4% in Experiment 1. This result especially contrasts with the results of Experiment 1 when considering the type of secondary task used in the two experiments. Participants in the study by Della Sala et al. simply watched and ignored abstract paintings, whereas participants in Experiment 1 performed a difficult speeded naming task. Others who have found an impact of visual perceptual input on visual short-term retention are Logie and Marchetti (1991), who demonstrated disruption of memory for colour hues by irrelevant pictures, and Tresch, Sinnamon and Seamon (1993), who demonstrated an effect of a concurrent colour discrimination task on a geometric shape memory task. Also, McConnell & Quinn (2003) found detrimental effects of DVN on visual short-term memory for shapes.

One tentative interpretation of these findings that is consistent with the workspace model is that the type of material used in these short-term retention tasks is likely to evoke strategies using long-term memory. The perceptual secondary tasks may then have had their disruptive effects because of the common requirement for the LTM activation process. Participants may have attempted to remember the colours in the Logie and Marchetti (1991) study by associating these to memories of coloured objects in their long-term knowledge base, and similarly, the complex matrices in the Della Sala et al. (1999) study and geometrical shapes in the Tresch et al. (1993) study may have been encoded in terms of shapes or patterns in LTM. In the McConnell and Quinn (2003) study, participants were instructed to hold the to-be-remembered material in a conscious visual image. This might have led participants to continuously refresh the image of the material in visual WM, possibly with the help of activating associated representations from LTM. A possible explanation for the interference found in these studies is therefore that the short-term retention may have involved the continuous activation and re-activation of representations in LTM rather than storage in the visual cache of a set of items that are within its capacity. The perceptual interference tasks may then have caused disruption because they also involve LTM activation that is required to supplement the capacity limited visual cache. The abstract paintings in the Della Sala et al. (1999) study may have activated LTM representations in an automatic attempt of the perceptual system to make sense of the meaningless material. Additionally, the paintings in this study were presented on paper cards, held in front of the participant by the experimenter. The same twelve cards were presented in each retention interval in random order. This changeover of cards would not have been very smooth, and could have made this visual interference material particularly disruptive. A DVN display on a computer screen would remove this possible disruptive effect of an experimenter handling the interference material.

This interpretation of the disruptive effects in the above studies in terms of the activation of LTM remains somewhat speculative and would require investigation in further research. The mechanism behind the disruptive effect on the colour hue memory task of Logie and Marchetti (1991) could be investigated by combining the same memory task with a visual interference task that is less likely than irrelevant pictures to involve LTM activation (e.g. DVN), which should then result in less or no disruption. It could also be argued that DVN is even less meaningful than abstract paintings. According to the workspace model, more meaningful material should result in a broader activation of LTM representations. Some results consistent with this hypothesis were provided by studies by Logie, 1986 and McConnell and Quinn (2000, 2004, see Section 1.5.2). The results of Experiments 4 and 5 in this thesis are also consistent with the suggestion that DVN poses less demand on the LTM activation process than irrelevant pictures would (this hypothesis is discussed in more detail in the next section).

No effect of tapping

Another inconsistency with the present results comes from studies that have demonstrated an *absence* of an effect of tapping on visual short-term retention. In Experiment 2, foot tapping was found to significantly disrupt recall of matrices, and in Experiments 6 and 7, tapping significantly interfered with recall of letter identity and case form. Pickering, Gathercole, Hall, and Lloyd (2001), for example, found that recall of static matrices was not impaired by the requirement of concurrent tapping in adult participants (even though recall was disrupted in a child participant group). The matrices used were very similar to those used in the present Experiments 1-3. However, presentation time was only 2 seconds, and recall was immediate. Participants tapped from 2 seconds before presentation of the stimuli, until the stimuli disappeared. The specific tapping task used was unseen tapping, following 4 buttons on a tapping board in clockwise direction. The procedure was therefore very different from the procedure used in Experiment 2 in this thesis. Given that recall was immediate, and tapping was carried out only during presentation of stimuli, it is perhaps not surprising that (in the adult population) tapping was not found to have an effect on visual short-term retention. Importantly, in their experiment, tapping also did not have an effect on a more spatial dynamic version of the matrix task. Moreover, the tapping pattern was much simpler than the pattern used in Experiments 2, 6 and 7, and could thus be argued to pose less of a demand specifically on visual working memory. Pickering et al. hypothesised that tapping could have had an effect in the child group because spatial tapping is much more attentionally demanding for children, and poses more of a load on executive resources.

Morris (1987) also found no effect of tapping on recall of static patterns. In the visuo-spatial memory task he used, participants were required to recall the locations of five filled circles randomly presented in a square. The circles were presented in one of the cells of a 9x9 matrix, but the matrix was not visible to participants (the circles were presented in a blank square) to minimise the possibility of verbal recoding. Participants responded by placing five crosses in a blank square on a recall sheet. The circles were presented serially, with a white homogeneous display presented in the inter-stimulus intervals. Stimulus duration was always 1 second, and the ISI 0.5 seconds. Recall was immediately after presentation of the fifth circle. For the tapping task, a box with an array of 5x5 keys was used, and participants had to follow the keys along one row, then reverse along the next row, and so on, during presentation of the stimuli. They had to press every key in the correct pattern at least once every tracking trial (which had a total duration of 10s). The box was out of view of participants. The tapping task appeared to significantly disrupt encoding. However, in a second experiment, a response delay was introduced of 10 seconds after the fifth stimulus presentation. When participants were required to tap during the retention interval, there was no effect on recall on the visual short-term memory task. In this second experiment, another interference task was introduced during the retention interval, namely a visual tracking task: participants had to follow with their eyes a sine wave with three peaks at least three times during a trial. This tracking task also did not have an effect on recall of the circle locations, even though eye movements have widely been shown to have a disruptive effect on visuo-spatial memory tasks (e.g. Myerson, & Abrams, 2004; Lawrence et al., 2001; Pearson & Sahraie, 2003; Postle et al., 2006). A possible explanation for the lack of effect in this second experiment could therefore be that retention in the main task was not demanding enough. The interference found in the first experiment could then be due to disruption of encoding of stimuli. Performance on the circle task was scored on a minimum error basis in terms of grid units, by reference to a transparent recall sheet with the 9x9 grid and the actual stimulus locations marked on it. Chance performance was determined to be 13.32 errors per trial. In control conditions, participants' average score was around 4 errors per trial, which indeed suggests that their performance was close to ceiling, and this would have made performance insensitive to any disruption.

Quite similar to Morris' (1987) results, other studies have revealed that the Brooks matrix task is affected by tapping movements during encoding, but not during a retention interval (e.g. Quinn, 1988a, b; Quinn & Ralston, 1986). In the Brooks matrix task, participants are presented auditorily with a number of sentences referring to the placement of digits that had to be imaged in a formation appropriate to a 5x5 mental matrix. Quinn and Ralston (1986) presented 9 sentences to participants, one sentence every 4 seconds. After presentation of the last sentence, participants were to recall the digits in the matrix by writing them down. While listening to the sentences, participants were instructed to tap with their right hand in a 5x5 matrix taped on the table and out of view. There were three different tapping conditions: (1) a compatible condition, in which participants followed the sequence described in the sentences (i.e. one tap every 4 seconds); (2) an incompatible condition, in which participants were instructed to always follow the same simple sequence (i.e. start in the starting square, move three squares to the right, one down, and then 5 to the left), and again one movement with each sentence presentation; and (3) a neutral tapping movement condition, in which participants simply tapped their finger in the starting square once with every sentence presentation. Only the incompatible movement condition resulted in a significant disruption of recall performance. Both neutral and compatible tapping did not have an effect. These results were replicated in a separate experiment in which the movements were passive, i.e. in which the participants relaxed their arms and the experimenter moved the participants' hand in the matrix. Again, only the incompatible condition was significantly different from the control condition (Quinn & Ralston, 1986). In further studies, Quinn (1988b) demonstrated that a fourth condition, a random movement condition in which participants moved their hand randomly from square to square with each sentence presentation) resulted in an even larger drop in performance, both when the movement was active and passive. Compatible or neutral tapping movements did not have an effect on recall (Quinn, 1988b). However, when a retention interval was introduced, none of the movements had any substantial effect (Quinn, 1988a). Again, the type of tapping task used was very different from the tapping task employed in the experiments in the present thesis. In most conditions of Quinn's tapping task, the patterns to be tapped were much simpler than the figure-of-eight tapping required in the present experiments. Moreover, participants only tapped once every 4 seconds, which would have made the tapping task much less demanding in comparison with the present experiments, in which participants tapped twice every second. This could account for the absence of effect of tapping during retention. The incompatible tapping could have had its interfering effect by disrupting encoding (rather than retention) of the digit positions. This is consistent with the hypothesis that there is an overlap between the cognitive systems that are involved in encoding and those that are involved in the control of active movement (i.e. an inner scribe component) (e.g. Logie, 1995). One problem with this explanation, however, is that in Experiments 5 and 6, tapping during encoding of the auditorily presented stimuli in the Letter Imaging task did not have a disruptive effect. A possible explanation for this inconsistency is that the stimuli in the Brooks matrix task would be more difficult to encode, because the mental placement of the digits in the matrix poses an extra spatial demand on this task. Salway and Logie (1995) demonstrated that the spatial version of the Brooks Matrix task during encoding and retrieval does indeed appear to require executive resources.

Logie and Marchetti (1991) demonstrated a double dissociation of interference of a tapping task with a spatial short-term memory task, and of a visual interference task (irrelevant pictures) with a visual short-term memory task. Their visual task was not affected by tapping. In this task, participants were presented with four squares in a rectangular arrangement on a computer screen. On any one trial, each square was shown in a different shade of a single basic colour. The squares appeared one after another at a rate of one per second, until all four squares were displayed. One second after the fourth square was shown, the squares disappeared and a blank screen was presented during a retention interval of 10 seconds. After the interval, four squares again appeared. On half of the trials, one of the squares was changed to a different shade of the same basic colour. Participants had to indicate whether or not the shades of the squares were identical to those in the initial display. In the tapping condition, participants had to tap during the retention interval, in an unseen 5 by 5 matrix taped on the table. The tapping pattern started in the second square of the second row, and participants had to follow the squares to the right, then down and to the left, then down again and to the right, at a rate of one square per second. Earlier this section, when trying to account for Logie and Marchetti’s demonstration of the irrelevant picture effect on this visual colour hue task, it was hypothesised that the colour memory task could be highly dependent on LTM. Participants may have attempted to remember the colours by associating these to memories of similar colours or coloured objects in their long-term knowledge base. This might also explain the absence of an effect of tapping. It is also possible that the change detection method used by Logie and Marchetti for assessing memory is less sensitive to disruption than is a recall method as was used for Experiments 2, 6 and 7. However, as indicated, this explanation remains speculative, and would require further investigation in future studies.

A last study in which no effect of tapping on a visual short-term memory task was found, is a study by Darling, Della Sala and Logie (2007). Participants in their study were healthy elderly volunteers (mean age 66 years). They were presented with a black screen on which 30 randomly positioned white squares were arranged. One of these squares was filled in with a letter P in a typeface that was randomly selected from a large set of examples. The P was always given in lower case form, and the P's from all different typefaces were scaled to be the same size. The P was visible for 0.5 seconds, after which the entire display was cleared and an interval of either 0.5, 5.5, or 15.5 seconds was imposed. After the interval, the white squares reappeared and a probe letter P was presented in one of them. This probe P could be presented in the original location, or in a different location, and could be presented in the original typeface, or in a different one. In the visual version of the task, participants had to decide whether or not the probe P was presented in the original typeface. In the tapping condition, participants were required to tap in the retention interval, on an unseen keypad with 9 keys arranged in a 3x3 array. The tapping pattern was a figure-of-eight, and tapping rate was one per second. Tapping did not have any effect on performance on this task, either measured in accuracy or reaction time of responses. This result seems in direct contrast with the present results, especially given the similarity of the tapping task used. It could be argued, though, that the Darling et al. visual task was much easier than the Letter Retention Task used in Experiments 6 and 7. In these latter experiments, participants had to remember four letters rather than one, and they had to remember letter identity, case form and order of presentation, rather than just the font type. This could explain the lack of effect of tapping. However, this explanation runs into difficulty when considering the results of another interference condition in the Darling et al. study; they found a significant effect of DVN on reaction times in the visual task. Moreover, the effects of tapping and DVN were the opposite for a spatial version of the task, in which participants had to decide whether or not the probe P was presented in the original location. Both the effect of DVN and the absence of an effect of tapping on the visual task are inconsistent with the results of the present experiments. These results are thus not easy to explain, but, like Logie and Marchetti, Darling et al. used a change detection paradigm, not a recall paradigm. Moreover, Darling et al. tested participants who were much older than those tested in Experiments 1-7 and it remains an open question as to how ageing affects the differential sensitivity to dual task interference. Therefore the Darling et al. experiments are not directly comparable with the experiments reported in this thesis.

11.1.2 Interference with imagery

The second important main finding of the set of dual-task experiments in this thesis is the demonstration of interference of irrelevant visual input with visual imagery. It was argued that visual imagery could be subdivided into the processes of (1) image generation – the activation of representations in LTM, and production of an image in visual WM on the basis of this activated material – and (2) the maintenance and manipulation of images held in visual WM (e.g. Pearson et al., 2001). Experiments 4 – 6 contrasted the effects of irrelevant visual input on these two processes. The letter imaging task was argued to heavily rely on the process of image generation, because it required participants to create a mental visual image of letters, drawn from representations in LTM. In contrast, the letter retention task was argued to depend critically on image retention in visual working memory, because the visually distinct letters (and their visually distinct case-forms) had to be remembered and subvocal verbal rehearsal was suppressed. In Experiment 5 it was demonstrated that performance on the image generation task was disrupted by the concurrent viewing of irrelevant pictures. The workspace model can account for this result in terms of the competition of these two tasks for the limited pool of cognitive resource for activation of stored knowledge. The gateway model could explain the result as well, by assuming that viewing pictures of concrete meaningful objects would result in the transfer of representations to long-term memory and activation of its contents, through the WM system. The unitary model could account for the result on the basis of its key assumption that attentional resources are limited (e.g. Cowan, 2005). The letter imaging task could be argued to be very attention demanding, because of its requirement for the image generation and manipulation process and speeded responses.

The only account of the disruptive effect of perceptual input on visual imagery that holds when looking at the results of Experiment 6, however, is the account of the workspace model. In Experiment 6 it was demonstrated that performance on the same image generation task was not disrupted by a spatial tapping task. In addition, the letter retention task was not affected by irrelevant pictures in Experiment 5, but was disrupted by spatial tapping in Experiment 6. As discussed in the previous section, the lack of impact of the tapping task on the image generation task is consistent with the workspace model, because tapping does not involve the activation of LTM. However, it involves the retention of the unseen visual tapping pattern in visual WM, and thus affects the image retention task. The workspace model could also account for the lack of disruption of visual short-term retention by irrelevant visual input, because retention of images in visual WM is thought to be independent of the perceptually driven activation of LTM. In contrast, the unitary model cannot account for the double dissociation in interference of the irrelevant pictures on image generation, and of spatial tapping on image retention. It could account post-hoc either for the results of Experiment 5 (by arguing that the image generation task is more attention demanding), or for the results of Experiment 6 (by arguing that the image retention task is more attention demanding), but these accounts would contradict each other. The disruption of the image generation task by irrelevant visual input in Experiment 5 could be accounted for by both the workspace and gateway model in terms of the common requirement for the LTM activation process. The gateway model, however, cannot account for the lack of disruption of the letter retention task by the irrelevant pictures, as discussed in the previous section. Therefore, only the workspace model is able to account for the combined results of Experiment 5 and 6. The interpretation of the workspace model for the selective effect of tapping on visual short-term retention was supported by the results of Experiment 7. In Experiment 7, the effect of tapping on the letter retention task was replicated, and it was confirmed that the tapping task selectively disrupted recall of the visual features of the retention task (i.e. letter identity and case form). These effects dissociated from the impact of a syncopated tapping task, which affected all measures of recall on the retention task (i.e. visual and spatial/serial aspects).

One possible alternative interpretation of the results of Experiment 5 that could be offered by the workspace model is based on the requirement of the image generation task for the operation of the central executive. The process of image generation was hypothesised to be dependent on the central executive (e.g. Logie, 1995; Pearson et al., 2001). The central executive has also been implicated in controlling and coordinating the two slave systems, the capacity to focus attention, to switch attention, to activate representations in LTM, and other complex cognitive tasks (e.g. Baddeley, 1996; Baddeley & Logie, 1999). It could thus be argued that dual-tasking in general is also heavily dependent on the central executive. In this view, the image generation task could have been more prone to interference by any other secondary task than the retention task is. However, like the account of the unitary model, this alternative account of the workspace model in terms of competition for central executive processes, runs into difficulty when trying to explain the double dissociation in interference effects in Experiment 5 and 6.

The results of Experiment 5 are consistent with previous demonstrations of the impact of irrelevant visual input on visual imagery tasks. The encoding and retrieval phase of the pegword mnemonic, for example, have been demonstrated to be disrupted by viewing visual matrix patterns (Logie, 1986), plain coloured squares (Logie, 1986), a moving dot (Quinn & McConnell, 1996a), a colour matching task (Zimmer & Speiser, 2002) and irrelevant pictures (Andrade et al., 2002; Logie, 1986; Quinn & McConnell, 1996b). One concern is that the majority of studies that have demonstrated disruption of imagery tasks by irrelevant visual input, have used DVN as the interference material. DVN has been demonstrated to disrupt the encoding and retrieval phase of the pegword mnemonic too (Andrade et al., 2002; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996a, 1996b, 1999, 2006), as well as a task involving visualising a route on a previously learned climbing wall (Smyth & Waller, 1998), an animal size comparison task (Dean et al., 2005), making true-false judgements about imagined objects or scenes (Dewhurst et al., 2004), and the method of loci (Quinn & McConnell, 1996b). Experiment 4 failed to replicate this widely demonstrated effect of DVN on imagery; DVN did not significantly disrupt the image generation task. It was argued that a possible explanation for this unexpected lack of interference effect is that participants showed some learning over trials in the generation task. This learning effect may have obscured any small interference effect of DVN. Additionally, DVN may have been too unstructured or meaningless to place a demand on the LTM activation process high enough to disrupt the generation task, which in turn may not have placed a very high demand on LTM activation either. The observation that most tasks that have been disrupted by DVN seem to be relatively complex and demanding tasks is consistent with this hypothesis. Especially the frequently used pegword mnemonic could be argued to depend very heavily on the activation of LTM, for the generation of complex visual images. The hypothesis that DVN may not have placed a high enough demand on the LTM activation process is further supported by the significant disruption of the same image generation task in Experiment 5 by irrelevant concrete pictures. The experimental design and procedure in the two experiments were identical, suggesting that there was a fundamental difference between DVN and irrelevant pictures. The argument here is that concrete pictures involve the extensive activation of representations in LTM (visual, verbal as well as semantic representations), more than DVN does.

Inconsistent findings

No effect of irrelevant visual input

Again, there are some inconsistent findings in literature, of studies failing to demonstrate an effect of irrelevant visual input on visual imagery tasks that depend on images from LTM. For example, Zimmer and Speiser (2002) found no effect of DVN on the pegword mnemonic, even when it was presented during the encoding phase. Also, Pearson et al. (1999) demonstrated a lack of disruption by DVN on performance of a mental synthesis task. In this task, participants were presented with the verbal labels of five previously learned geometric shapes (drawn from a set of 15 in total). They then received two minutes to attempt to generate an image, which combined all of the presented shapes so as to form a recognisable object or pattern. After this period, participants were asked to give a short verbal description of the resulting imaged pattern, and then to draw their pattern on paper. During the two minutes, participants either received no interference, or they were required to look at a DVN display. DVN appeared to have no disruptive effect on performance of participants on this creative synthesis task. A tentative explanation for this lack of interference could be that the process of image generation only takes place when participants retrieve the visual representations of the geometric shapes from LTM when they are presented with their verbal labels. Once these shapes are available in WM, they can be further manipulated. The visual cache is proposed to have a role in storage of material during the synthesis, whereas the manipulation (the creative synthesis) is thought to be heavily dependent on the inner scribe and central executive for the control of manipulations and the continued maintenance and inspection of the images (Pearson et al., 1999). During the two-minute manipulation process, image generation is not required any longer. This could explain why the irrelevant visual input has no effect during the construction phase of the task. This explanation is speculative, however, and would need formal testing, by investigating the effect of DVN (and other types of visual interference) during the different stages of the synthesis task.

Effect of tapping on imagery

In contradiction with the present results (in particular Experiments 4 – 6), some studies have demonstrated an effect of tapping on visual imagery tasks. Tapping has, for example, been shown to interfere with the encoding phase of the Brooks matrix task (as discussed in the previous section, Quinn, 1988b; Quinn & Ralston, 1986), with mental synthesis (Pearson et al., 1999), with mental rotation (Logie & Salway, 1990), with encoding of relative sizes (Engelkamp et al., 1995), and with the construction of mental spatial models (Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007). All these imagery tasks, however, could be argued to pose a relatively heavy load on visual short-term memory and on executive resources, in addition to the image generation process. In contrast, the imagery task used in the present experiments did not place such a demand on visual retention or complex encoding or manipulation processes. As noted earlier, Salway and Logie (1995) demonstrated the high executive load in the Brooks matrix task. In the encoding phase of the Brooks matrix task, for example, participants listen to the sentences describing the placement of the digits in the matrix. Sentences are presented only once every 4 seconds (e.g. Quinn & Ralston, 1986), which makes the duration of the ‘encoding’ phase of this task at least 36 seconds, and which leaves considerable time in between sentences, for participants to visualise the matrix and rehearse the digit locations. This aspect of the task would draw on maintaining the image in the visual cache component (and rehearsal on the inner scribe) and therefore tapping would have a disruptive effect. During the retention interval, it is highly likely that, as with the peg word mnemonic, memory for the layout of the pathway around the Brooks matrix would rely on passive storage in long-term memory, and that working memory would be involved only during encoding and retrieval. This would account for the lack of an effect of tapping during the retention interval in the Brooks task (Quinn, 1988a). In Pearson et al.’s (1999) mental synthesis task there was also a load on the visual cache component. It was argued that the visual cache has a role in storage of material during the synthesis (Pearson et al., 1999). Their tapping task was very similar to the tapping task used in the present experiments: participants tapped on an unseen 3x3 tapping board in a figure-of-eight pattern, at a rate of 2 taps per second. In the tapping condition, participants produced significantly fewer patterns in the synthesis task and also recalled all of the presented parts in (marginally significantly) fewer trials. The tapping could thus have disrupted maintenance of the presented stimuli in the cache. Moreover, the mental synthesis itself is thought to heavily depend on the inner scribe and central executive for the control of manipulations and the continued maintenance and inspection of the images (Pearson et al., 1999). The tapping task could have further interfered with the synthesis task because of competition for these executive resources. The Letter Imaging task would have placed less of a demand on these manipulation processes, as the mental images only needed to be inspected briefly. The effects of tapping on mental rotation (Logie & Salway, 1990), on encoding of relative sizes

(Engelkamp et al., 1995) and on encoding spatial relations (Gyselinck et al., 2007) could be explained in a similar fashion. Logie and Salway (1990) reported that tapping significantly disrupts participants' accuracy during the mental rotation of abstract shapes. Engelkamp et al. (1995) found that tapping disrupted the construction of a linear size order (mental comparison of objects' sizes) on the basis of pictorial stimuli. In the Gyselinck et al. study, participants had to read texts describing a specific route in an environment. They were instructed to either use a mental imagery or verbal repetition strategy to help them comprehend the descriptions. Their comprehension was tested in a verification task, in which participants had to judge whether statements describing spatial relationships between landmarks were true or false. In the tapping condition, participants tapped during reading of the texts, in counter clockwise direction on four buttons, at a rate of 1 tap per second. The tapping board was placed out of sight of the participant. Tapping significantly impaired performance on the verification task when texts had been read with imagery instructions, but not when participants read with repetition instructions. Again, all of these tasks could be argued to depend on maintenance of the images in the visual cache, as well as on executive sources for encoding and manipulation of the material, and these processes are interfered with by concurrent tapping.

Another study that has demonstrated an effect of tapping on mental imagery is the study by Baddeley and Andrade (2000). In this study, participants were presented with either a novel array of geometrical shapes or with a novel sequence of tones, for 5 seconds, then had to hold an image of these stimuli in mind during a retention interval of 6 seconds. After this interval they had to rate the vividness of their mental image according to a rating scale that was presented for 5 seconds. After a second interval of 4 seconds participants then had to compare their mental image to a probe stimulus, which could be the same or different from the initial stimulus. In the tapping condition, participants tapped throughout presentation of the stimuli until the memory task response was to be made, and only pausing in between to make the vividness rating. Participants tapped on a 3x4 keypad proceeding along each row and returning on the next, without looking down at the keys. Tapping was found to have a detrimental effect on the visual imagery ratings, but no effect on visual memory task performance. The effect of tapping on vividness ratings was replicated in subsequent experiments using different types of stimuli (e.g. pictures from magazines or scenes from long-term memory cued by verbal descriptions) and different tapping patterns. Tapping thus only had an effect on the subjective ratings of vividness of mental images, not on the actual imagery performance. There are no specific predictions from the unitary or the workspace model as to what cognitive resources would be required to generate vividness ratings. Also given that vividness ratings are based on subjective judgements, they could be based on expectations by the participant that a secondary task ought to interfere rather than on any objective criteria, a caveat that Baddeley and Andrade consider but do not fully address. Therefore, these results are not necessarily inconsistent with the present results.

Alternative account

The present experiments contribute importantly to the body of evidence for the sensitivity of imagery tasks to irrelevant visual input, and to the discussion about the theoretical interpretation of this observation. Several researchers have attempted to account for the selective interference effects of irrelevant visual input on visual imagery tasks, but not visual short-term memory tasks (e.g. Andrade et al., 2002; Avons & Sestieri, 2005; Quinn & McConnell, 2006; Zimmer & Speiser, 2002). By making the distinction between the image generation and retention processes within imagery tasks, the workspace model is able to explain this dissociation in effects of irrelevant visual input, better than other interpretations that have been offered. It interprets the resistance of visual short-term memory against interference in terms of the independence of WM retention and LTM activation. The disruption of imagery is interpreted in terms of interference with the image generation process, which involves activation of LTM, as does visual perception. One alternative interpretation for the selective effects of irrelevant visual input on imagery that has been offered repeatedly, assumes that visual short-term memory and visual imagery are mediated by two different storage modules (e.g. Andrade et al., 2002; Quinn & McConnell, 2006). Different authors have coined different terms for these components, but the general agreement seems to be the suggestion of, on the one hand, a passive, non-conscious store for short-term retention, and on the other hand, a more active, conscious store for visual imagery. The selective interference effects of irrelevant visual input are then explained by assuming that only the store for imagery is susceptible to interference (Andrade et al., 2002; Quinn & McConnell, 2006). This interpretation implies a gateway view of obligatory access of perceptual information to the WM system, which is inconsistent with the findings of Experiments 4 – 6. Moreover, this ‘dual-store’ view cannot account for the combined results of especially Experiments 5 and 6. It could be argued that in Experiment 5, the letters of the retention task were stored in the visual short-term memory store, where they would be protected from interference, whereas the generation task relied on processing in the conscious imagery component. This interpretation runs into difficulty when trying to explain the results from Experiment 6. In this experiment, the imagery component appeared susceptible to interference, whereas the short-term memory store was not. The results of these two experiments are thus incompatible with the assumption of two separate memory stores for passive retention and active imagery.

11.1.3 Limitations of experiments and methodology

A few limitations of the methodology used in the present experiments should be discussed. These limitations do not undermine the findings, but rather provide directions for the development and improvement of the methodology and paradigm for further research. A first limitation is the choice of visual short-term memory task in Experiment 1. Matrix pattern memory tasks have been used frequently as visual tasks (e.g. Andrade et al., 2002; Della Sala et al., 1999), but a discussion in the literature focuses on the distinction between 'visual' and 'spatial' in this respect. Some researchers have argued that remembering a spatial layout of items (like cells in a matrix) should be regarded as a spatial rather than a visual task (e.g. Mecklinger & Müller, 1996; Postma & De Haan, 1996; Zimmer et al., 2003). Moreover, performance of this task is likely to benefit from encoding in LTM of recognisable shapes in the patterns (e.g. Kemps, 2001), on the basis of continuity, symmetry or another kind of structure. In fact, it was argued that this might be one possible reason why there was a significant effect of irrelevant pictures on performance on the visual patterns task. If participants indeed employed a LTM strategy to remember the patterns, then the irrelevant pictures might have interfered because they activate LTM as well. The arguments in this thesis would be strengthened if the results of the experiments using the visual patterns task were replicated using a task that was more clearly visual in nature, and less likely offered participants the possibility to use LTM in performance of the task.

The results of Experiment 1 alone could be explained by all three models. It is the combination of the results of Experiments 1 and 3 which provided stronger support specifically for the workspace model. Even though the design and procedure of both experiments were identical, it is possible that there were small differences between the experiments in material set-up, participant group, instructions, or other variables that could have influenced performance levels. Replication of the results using a within-subjects design, in which each participant carries out both types of secondary task (picture naming and letter imaging) would offer a more powerful and better controlled experiment. Having only one baseline performance level against which the two interference conditions could be compared, would result in a more sensitive and justified comparison of the effects of the two secondary tasks.

In Experiments 4 – 6, it was attempted to design an image generation task that would rely on images from long-term memory. The letter imaging task was chosen because this task had been used repeatedly in the imagery literature (e.g. Kosslyn et al., 1993), and because letters have a standard visual appearance which everyone is highly familiar with. To make the retention and generation task maximally comparable, a retention task was designed that also used letters. This task is perhaps less suitable as a strictly visual task, because verbal coding in retention of the letters might have been possible to a certain degree. It is true that the letter retention task has been extensively tested, and has been demonstrated to rely on visual short-term memory (Logie et al., 2000). Moreover, the results of Experiment 7 have confirmed that the task relies on memory for the visual features of the letters, even when no articulatory suppression was required. However, using a task that is more clearly visual, and would not require the use of articulatory suppression, would make the design of this experiment neater and more compelling. Future research could focus on developing a set of tasks relying on the processes of image retention and generation that are purely visual and use similar material, while using a visual perception task and a visual working memory task that are also equated in terms of material and requirement for attention.

A further limitation of the letter imaging and retention tasks in Experiments 4 – 6 is that they differ in terms of the phase in which the interference material was presented; in the image retention task, the irrelevant pictures were presented (and tapping was executed) in the retention interval, after encoding of the visually presented letters, whereas in the image generation task, the interference tasks were presented during presentation and encoding of the letters to-be-imagined. Even though it is unlikely that this might have had an influence on the results, the design would be more elegant if the retention and generation task would be more similar in this respect as well, and the interference material would be presented during the same phases of both tasks. In the current experiments, the fact that the pictures were presented during the presentation of the letters in the generation task, but after presentation in the retention task, could not have contributed to the interference effect found, because the effects of tapping dissociated with the effects of the pictures, while the tapping was presented in the same phases of both tasks as the pictures were. Nonetheless, it would be more consistent to present the interference material during the same phases of both main tasks, e.g. to present irrelevant visual input between the presentation of individual to-be-remembered items in the retention task.

11.1.4 Conclusions

The present experiments aimed to compare the three types of models of the interaction between WM and LTM, by testing their specific predictions about the effects of irrelevant visual input on different visual WM tasks. The results from the experiments are most consistent with the predictions of the workspace model; this model is able to give a coherent account of all results. The experiments have presented with powerful arguments against both the gateway and unitary model of WM. The relative immunity to interference by irrelevant visual input of visual short-term retention suggests that there is no direct access of perceptual information to visual WM, as assumed by the gateway model, and as suggested by researchers such as Quinn & McConnell (2006). The unitary model, in turn, is unable to account for the double dissociation of interference effects of irrelevant visual input on image generation, and of tapping on image retention. These experiments have thus contributed to the body of evidence from neuropsychology, and from experiments investigating mental creativity and synthesis, to point to a model in which perceptual input activates stored representations in LTM prior to the product of that activation being transferred to and maintained in a separate mental workspace. The present experiments also provide a foundation for future research to replicate and extend these results. More empirical research in this area is important especially in the context of the inconsistencies found in the literature on interference with visual working memory, and the ongoing debate about the theoretical interpretation of these effects. Moreover, it appears that only through carefully designed experiments can the debate about the functional relationship between WM and LTM be resolved, and that advances can be made in the development of theories that model this relationship.

11.2 EXPERIMENT 8

11.2.1 Accounts of the three models

Experiment 8 was designed to further test the three models of the interaction between WM and LTM, by investigating the phenomenon of unconscious high-level processing of visual material in neglect patients. The gateway model has difficulty interpreting this phenomenon, whereas the unitary and workspace model can account for it more readily. Experiment 8 confirmed specific predictions about implicit semantic processing made by these latter models. The findings will be discussed in detail, after briefly summarising the accounts (and difficulties) of the three types of models for implicit semantic processing of visual material (see Sections 1.4.1 and 9.1 for more detailed discussions on the models' interpretations).

The account of the workspace model for the phenomenon of implicit processing of visual material by neglect patients is based on the key assumption of this model that perceptual input first activates LTM, and that the activated LTM traces can be made available in the WM system for further processing. Perceptual input in neglect patients is degraded due to the attentional impairment, but is assumed to still activate representations in LTM sufficiently to influence behaviour. The activation is not sufficient to allow for the construction of a complete conscious visual representation in visual WM, resulting in a lack of conscious awareness for the stimuli (e.g. Della Sala & Logie, 2002; Logie, 1995; Logie & Della Sala, 2004, see also Section 1.4.1). In the gateway view of WM, the activation of LTM by visual perceptual information that is not represented in visual WM, could only be accounted for by an extra fast-track in the model from perceptual input directly to LTM. This would result in a 'leaky gateway' (Della Sala & Logie, 2002), and a less parsimonious model than the workspace or unitary model. The unitary model proposes that WM constitutes the currently activated traces in LTM. In this view, perceptual information that activates LTM would automatically be part of WM as well. As a solution, Cowan (e.g. 1999; 2005) proposes that also activated LTM traces of which one remains unaware can be part of WM, and that only the activated traces that are in the focus of attention reach consciousness. The activated LTM traces outside of the focus could still influence behaviour.

11.2.2 Implicit processing depends on activated LTM

Experiment 8 tested the assumption of the unitary and workspace models that implicit processing relies on pre-existing representations in LTM. The critical feature of the experiment was the manipulation of the familiarity of the stimuli. A wider network of representations in the knowledge base of previous experiences should be available for familiar, meaningful visual stimuli than for unfamiliar visual stimuli. Therefore, the unitary and workspace models would predict that familiar stimuli can be processed implicitly better than unfamiliar stimuli. A paradigm of matching complex pictures with auditorily presented verbal information (i.e. proverbs) was used. Results confirmed the predictions of the unitary and workspace model for implicit processing: one patient, CK, implicitly processed neglected parts of images depicting common British proverbs but not of images depicting unknown foreign proverbs. The measure of implicit processing was the matching performance of the pictures with the correct proverb from a list of four. In CK, the neglected part of the pictures of familiar proverbs thus appeared to have activated LTM representations associated with the proverb, sufficiently to implicitly 'guide' his proverb selection. The pictures of unfamiliar proverbs did not lead to correct proverb selection, even though these pictures contained individual items, the names of which were also present in the proverbs. There was thus no evidence for semantic priming of these key words by the pictures. These results suggest that only the activation of the rich representations of the complete familiar proverbs, containing visual, verbal and semantic information, as a result of implicit perception of the pictures, was sufficient to influence CK's responses implicitly. This observation is consistent with the predictions and interpretation of the unitary and workspace models, and suggests that LTM can be activated by perceptual information that is not represented in the WM system (or the focus of attention).

This result also converges with the results of the dual-task experiments, suggesting that the meaningfulness or familiarity of visual perceptual information influences its further processing in the WM system, pointing to a model in which perceptual information first activates representations in LTM before this activated information becomes available in WM. In particular, in Experiments 4 and 5 it was demonstrated that DVN, which is meaningless and unstructured, did not affect a visual imagery task, whereas concrete irrelevant pictures did have a significant impact on the same imagery task. This difference was interpreted in terms of the more widespread activation of LTM by the meaningful concrete pictures (see also the previous section). In Experiment 8, the same relation between meaningfulness of perceptual input and its activation of LTM and further processing was demonstrated. Such a relation would be difficult to explain with the gateway model, in which perceptual input has direct access to the WM system for further processing, and would thus not depend so much on the meaning or familiarity of the input.

11.2.3 Implication for neglect patients

Although the aim of Experiment 8 was to address the different models of the relationship between WM and LTM, and not to study implicit processing in the neglect syndrome as such, one practical implication of the present results for perceptual neglect patients is considered here, namely for rehabilitation. The present results suggest that not all access of perceptual information to LTM is impaired in perceptual neglect patients, and the ability of some patients to process visual information implicitly could be capitalised on. Since (by definition) neglect patients do not become aware of the implicitly processed information, they could be trained to become more sensitive to the implicit ‘knowledge’ by trusting their intuition or by guessing, for example in searching for objects in their environment. CK thought he was making pure guesses, yet his performance was significantly above chance level. Patients could be encouraged to use the implicit knowledge this way, even though it feels like they are just guessing, and learn to exploit the implicit perception for use in their daily lives. Other researchers have also considered the applicability of the phenomenon of implicit processing in rehabilitation. Vuilleumier et al. (2002b) demonstrated that neglect patients are able to learn about stimuli that escape their awareness, without realising that they are doing so, and proposed that this learning could be capitalised on in rehabilitation. Forti and Humphreys (2004) described how they capitalised on the ability of implicit processing in a patient by coupling attention to the affected visual field with action in this area (arm movements). They suggested that the coupling of action to attention increased any activation from stimuli in the contralesional side of space, enabling the patient to detect them more easily (Forti & Humphreys, 2004). Wilson, Baddeley, Evans and Shiel (1994) found that errorless learning in amnesic patients was more successful than errorful learning when it was used as a training program for the purposes of rehabilitation. In the study phase of this experiment, amnesic and control participants were presented with lists of word stems and they were either required to guess the word (which permitted incorrect responses) or were provided with the complete word (preventing incorrect responses). After the study phase, participants were asked to recall the words which had been presented in the study phase, in an explicit cued recall task (stem completion). The amnesic participants performed significantly better in the errorless learning condition than in the errorful learning condition. Wilson et al. argued that the amnesic patients were heavily reliant on implicit learning, and that this type of learning is particularly susceptible to interference, and is therefore not well equipped to deal with errors (Wilson et al., 1994). An implication of these findings for rehabilitation of neglect patients may be that if visual or spatial properties of left-sided objects are to be learned as effectively as possible, contamination of implicit perception should be prevented, for example by correctly guiding patients in their attempts to locate objects. Faulkner and Foster (2002) doubt the usability of the ability of implicit processing in rehabilitation of patients with neuropsychological disorders. They argue that it seems questionable whether in many everyday situations implicit processing would be of significant benefit for these patients, because of the very nature of this processing; by definition, implicit processing is not governed by conscious control (Faulkner & Foster, 2002). The ability of implicit processing might not be useful for the personal insight of an individual patient. However, without attempting to make a perceptual neglect patient aware of their ability to process visual stimuli implicitly, this ability could still be used indirectly for training purposes in rehabilitation. Future research should focus on identifying ways to implement the ability of implicit processing in rehabilitation, and determine its usability and practicability.

11.2.4 Limitations of experiments and methodology

Experiment 8 has demonstrated that the approach of studying implicit processing in neglect patients is a fruitful approach in the empirical investigation of the interaction between WM and LTM. It is therefore worth pursuing this approach in future research, using the methodology of carefully manipulating the visual and semantic content of the stimuli. However, a few limitations of the present experiments should be remarked on, which could also be addressed in future research. One limitation of the paradigm is that it was impossible to assess exactly when a patient was or became aware of certain information in the pictorial stimuli. As mentioned in the discussion of Experiment 8 (see Section 10.6), evidence for implicit processing by CK was found when the data were analysed according to a criterion of unawareness that has always been employed in the literature. It was argued that when using this criterion (of assessing awareness for the pictorial stimuli only before a response is made), it could be possible that CK had become aware of the target features to some extent, between describing the pictures and making a response. This explicit information from the left side of the pictures could then have been sufficient to support proverb selection, but not sufficient for him to motivate the reasons for his selections. Information can indeed be explicitly available to a certain extent, sufficient to support some forms of decision making, but insufficient to give the perceiver confidence to report the information overtly (e.g. Hannula et al., 2005; Reingold & Merikle, 1990; Verfaellie et al., 1995). During the extra assessment of awareness after a response was made (and thus using a stricter criterion), the information could have been processed further into awareness, allowing CK to overtly report the target features. If CK indeed became aware of the target features in the pictures before making a response, he must have made his responses on the basis of (partially) explicit information, and no claim of implicit semantic processing could then be made.

This analysis on the basis of a stricter criterion of unawareness is intriguing, because it offers an alternative account of previous findings of implicit semantic processing in the literature, where no such extra measure of awareness has been used. It could be possible, that studies using a similar paradigm of presenting patients with complex visual stimuli (under unlimited presentation time) about which they had to make certain decisions, actually measured (degraded) explicit processing, and not implicit processing. Studies using the 'burning house' paradigm could be interpreted this way. In the study of Doricchi and Galati (2000), for example, patient LP was asked to indicate whether two items, one damaged, were the same or different. When she did not notice the difference, she was asked which item she preferred. LP preferred the undamaged item far above chance, both when this was the asymmetrical or the symmetrical item. Doricchi and Galati did not report having asked LP whether the items are the same or different *after* she indicated her preference. The results of the present experiment suggest that it could be possible that in this case, LP would have been able to detect the difference. Likewise, the results of studies using chimeric pictures could be interpreted this way (e.g. Buxbaum & Coslett, 1994; Peru et al., 1996, 1997; Riddoch et al., 2003; Vallar et al., 1994). It appears that more control of awareness (i.e. a more accurate and reliable measure of unawareness) is needed in studies that employ paradigms of the kind described above.

An additional issue with Experiment 8 is that there was no assessment of participants' individual knowledge of the British proverbs, which were assumed to be familiar on the basis of pilot studies. However, knowledge of proverbs may vary among people depending on their educational background, personal interests, etc. These issues should be addressed in follow-up studies. A paradigm could be used that is less complicated than the present one, so that it becomes possible to control more reliably for conscious processing and assess awareness of patients for the stimuli. Also, material should be used which can be manipulated for familiarity more accurately, and which is not likely to vary with individual differences between participants, e.g. pictures or names of well-chosen faces of famous and non-famous people.

11.3 WIDER THEORETICAL IMPLICATIONS

11.3.1 The multi-component working memory model

The view emerging from the experiments presented in this thesis, of perceptual input activating representations in long-term memory prior to that activated information being made available to the WM system, has consequences for some of the assumptions of the multi-component model of WM (e.g. Baddeley, 2002; Baddeley & Hitch, 1974). It was argued that this model embodies the gateway view: perceptual information is thought to be able to accesses WM directly (see Section 1.2.3). Direct access of perceptual input to WM has not only been suggested for the visual domain (e.g. Baddeley, 2007; McConnell & Quinn, 2004; Quinn & McConnell, 1996b; 2006), but also for the verbal domain, namely in the irrelevant speech effect (e.g. Salamé & Baddeley, 1982, see also Section 1.2.3). The irrelevant speech effect refers to the disruption of verbal serial recall by concurrent irrelevant speech sounds. This effect has generally been interpreted as the direct access of auditory perceptual information to the verbal WM system (i.e. the phonological store), even though the precise mechanism is still much discussed (e.g. Hanley & Bakopoulou, 2003; Larsen & Baddeley, 2003; Neath, 2000). If working memory indeed acts like a workspace that deals with the activated contents of LTM, and that is not directly loaded by perceptual input, then there has to be an alternative explanation of the irrelevant speech effect. One interpretation that is consistent with the workspace view would be that the auditory perceptual input first activates phonological representations in LTM, and that this activated material is automatically transferred to verbal WM for further processing. It would make sense from an evolutionary point of view, that only certain perceptual information, namely the information that is relevant and meaningful, should be transferred for further processing, even when it might not have been attended to initially. There is some research that supports this hypothesis, demonstrating that only sounds that have certain similarity to speech sounds have the disruptive effect on verbal recall (for review see Larsen & Baddeley, 2003). Colle and Welsh (1976), for example, demonstrated that recall was affected by unattended speech in a foreign language, but not by noise. Similarly, Salamé and Baddeley (1982) found that recall was disrupted by nonsense syllables, meaningful words or digits (see also Jones, Macken & Mosdell, 1997; Tremblay, Macken & Jones, 2000), but not by noise that was modulated so as to produce the same sound intensity envelope as the speech (Salamé & Baddeley, 1982) Also, a disruptive effect was found of sounds whose frequency fluctuated in the same manner as the irrelevant speech (e.g. Jones, Macken & Murray, 1993). This could be interpreted as an auditory counterpart of dynamic visual noise, which was argued to activate visual representations in LTM because the perceptual system attempts to make sense of otherwise meaningless input (see Section 1.5.2). It therefore seems that the more meaningful or speech-like the auditory perceptual input is, the stronger the 'irrelevant speech' effect on verbal recall is. This interpretation, however, is speculative and would need proper experimental investigation, manipulating the sound properties according to the hypothesis.

Another consequence of the view of WM as a workspace for the multi-component WM model, is that the process of transfer of information from LTM to WM might even be more important than previously assumed. Baddeley proposed an important role of temporary activation and retrieval of LTM material to the WM system in tasks like prose recall or in the performance of memory experts (e.g. Baddeley, 1996). In the workspace view, however, the transfer of LTM information to WM would be required in all perception processes, when there is a requirement to remember or manipulate the perceptual input. The component that has been proposed to play an important role in the interaction between LTM and WM is the episodic buffer. When adding the episodic buffer to the multi-component model, Baddeley (2000) assumed it is involved in feeding information into and retrieving information from episodic LTM and thus provide a temporary interface between the slave systems and LTM. However, this role is in the storage of the information from LTM, rather than in the process of retrieval. Baddeley (2000) proposed that long-term information is downloaded into the separate temporary episodic buffer store. The episodic buffer is assumed to be controlled by the central executive, and could be seen as the storage component of the central executive. Presumably it would thus be the executive component responsible for the process of retrieval itself. This is consistent with the suggestion that the central executive acts as the host of an imagery buffer, used for the generation of images in WM, and the conscious experience of these images (Logie, 1995; Pearson, 2001).

There has not been much research that has directly investigated the specific role of the central executive in retrieval of information from LTM. Some studies have provided evidence for the role of the central executive in imagery, demonstrating that imagery is highly demanding upon attentional resources (e.g. Bruyer & Scailquin, 1998; Engelkamp et al., 1995; Logie & Salway, 1990; Pearson et al., 1996; Salway & Logie, 1995). These experiments did not elucidate, however, exactly which process(es) of imagery are attention demanding and require the operation of the central executive (activation of LTM, retrieval of information from LTM, the inspection of a conscious image in visuo-spatial WM?). Baddeley (2002) has, in fact, argued that retrieval from LTM does not appear to depend heavily on the executive. He bases this claim on a series of experiments in which a demanding secondary task was imposed on participants during the process of learning and/or retrieving lists of words. It was found that although concurrent load had a clear effect on learning, it had little influence on recall accuracy (i.e. retrieval from LTM) (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). These experiments only addressed retrieval of recently learned verbal word lists from LTM. The role of the central executive in retrieval of information from LTM is thus an area that further research could contribute to importantly. One way of investigating the role of any cognitive system in specific processes is by disrupting its function by placing a secondary load on it. An example of a secondary task assumed to draw on the function of the central executive, and that has often been used in studies to investigate the role of the executive, is random generation (e.g. Baddeley, 1998; Towse, 1998; Vandierendonck et al., 1998). Another approach of investigating the role of the central executive in LTM retrieval is by using neuro-imaging techniques or studying neuropsychological patients with executive problems. There is already well-documented evidence that certain prefrontal brain areas are important for executive functions, as well as in the retrieval of LTM (e.g. Braver et al., 2001; Ranganath et al., 2003). This could thus be a fruitful approach in the assessment of the role of the central executive in LTM retrieval. Furthermore, understanding the functioning and role of the episodic buffer component is also important, as its proposed role in the interaction between LTM and WM is at the core of the issue addressed in this thesis. Recently researchers started to investigate the role of the episodic buffer in feature binding in WM (e.g. Allen et al., 2006), but the role of the buffer in retrieval of information from LTM has not yet been addressed experimentally.

11.3.2 Short-term memory system and store

The view that emerges from the arguments and data set out in this thesis also has an implication for the ongoing debate about the existence of separate stores for short-term memory and long-term memory. (e.g. Cowan, 1995; Logie & D'Esposito, 2007; Miyake & Shah, 1999; Neath et al., 2005; Ranganath & Blumenfeld, 2005). Both the gateway and workspace model are based on the assumption of separate short- and long-term memory systems, whereas the unitary model embodies the view that there are no distinct short-term stores for short term retention of information. It is important to dissociate the theoretical distinction between STM and LTM on a cognitive psychology level (i.e. separate short- and long-term memory *systems* or *processes*) from the distinction on a neuro-anatomical level (i.e. separate *stores* in the brain). The workspace model is a cognitive psychology model of WM and LTM, and as such proposes the *functional* separation between WM and LTM. The workspace model does not make explicit claims about the separation on a neuro-anatomical level, but would be consistent with this view (e.g. Logie, 2003). In contrast, the unitary view is based on the assumption that STM and LTM are implemented in one unitary store (i.e. short-term retention is achieved by the temporary activation of long-term memory representations). Some researchers have also argued that there is no need to postulate distinct short-term memory *systems* (e.g. Crowder, 1993, Nairne, 2002). Not all researchers that adopt a unitary view, however, do also assume separate short- and long-term memory systems (e.g. Cowan, 1995; 2003; Ruchkin et al., 2003). Cowan (1995) for example, concludes that although many short- and long-term memory phenomena can be made to mimic one another, there are subtle but important differences between them, so that a distinct short-term memory function is still needed.

Proponents of the unitary view assume that short-term retention of visuo-spatial or verbal representations relies on the temporary activation of the same neural structures that are involved in the perception of this information (e.g. Postle, 2007; Ruchkin et al., 2003; see also Section 1.3.2). In this view, a visual short-term retention task should be disrupted by a concurrent task involving the perception of visual information. The present experiments have provided evidence that this is not the case, and that a visual WM task appears insensitive to disruption from visual perception. A better interpretation of the results would be to assume specialised storage components for short-term retention, which are separate from perceptual and LTM systems. This view would have an implication for the unresolved issue of the interpretation of the neuro-imaging data on WM retention, discussed in Section 1.4.2. It was argued in this section that there are broadly two possible interpretations of the data in terms of the location of WM storage in the brain. The first interpretation, consistent with the unitary model, is that storage of information in short-term (or working) memory tasks takes place in posterior areas, which are also involved in the initial perceptual processing of this information. The second interpretation, consistent with the workspace model, is that posterior areas are involved in the perception of information, but that WM retention takes place in prefrontal areas (Logie and Della Sala, 2003). The data presented in this thesis are most consistent with the second interpretation.

The present results are also inconsistent with the ‘extreme unitary view’ of only one memory storage *system*. Researchers have based this view on the observation that the same memory phenomena are associated with both short- and long-term memory, and the conclusion that it is therefore redundant to postulate two different systems (e.g. Crowder, 1993; Nairne, 2002; see also Section 1.3.1). The findings discussed in this thesis would favour an interpretation of the phenomena that have been observed to be similar in STM and LTM, in terms of similar but separate systems. One similarity between short- and long-term memory that has been taken as an argument for a unitary memory system is the observation that interference can account for all forgetting (see Section 1.2.1). This observation is for most researchers no reason to assume that there is only one memory system (e.g. Anderson, 2003; Lewandowsky et al., 2004). Moreover, there is still a debate about the role of decay specifically in short-term memory forgetting (e.g. Altmann & Gray, 2002; Anderson, 2003; Cowan, 2003; Nairne, 2002; Page & Norris, 1998). Also, the Hebb effect has been taken as evidence for the unitary model, because it demonstrates that long-term learning also occurs in a short-term memory task (see Section 1.3.1). However, others have stressed the interpretation of this result in terms of separate memory stores (and hence systems) (e.g. Burgess & Hitch, 2005). A third similarity between STM and LTM is the presence of a recency effect in serial recall. Also this finding is not inconsistent with the view of short-term memory as a system that is functionally separate from long-term memory. Davelaar et al. (2005; 2006), for example, review evidence showing that recency effects in short-term and long-term memory have different properties. They suggest that two memory components are needed to account for the recency effects (Davelaar et al., 2005). Finally, the observation that similar memory codes (i.e. both semantic and phonological) are used both in short- and in long-term memory was used as an argument for the unitary view, but again, this observation does not logically lead to the conclusion that STM and LTM must then reflect the operation of a single system. In fact, it is assumed that both semantic and phonological components in short-term memory are essential for the long-term learning of corresponding representations in long-term memory (e.g. Baddeley, 2003). Freedman and Martin (2001) have studied aphasia patients with deficits in short-term retention of either phonological or semantic information. They demonstrated that four of the five patients demonstrated long-term learning deficits in a paired associate paradigm that corresponded to their STM deficit.

11.4 OVERALL CONCLUSIONS

The main aim of this thesis was to investigate the interaction between WM and LTM, by comparing three different types of models of this interaction, namely the gateway model, the unitary model, and the workspace model. In the gateway model, all perceptual information is represented in the WM system before activating LTM. The unitary model assumes that WM is simply equal to the currently activated parts of LTM. In the workspace model, perceptual information first activates LTM, and this activated material can be transferred to a separate WM system for further processing. The results from the experiments in this thesis are most consistent with the workspace model. This support for the workspace model is particularly powerful because it comes from different approaches, using different experimental paradigms and techniques. In particular, the cognitive psychology experiments have demonstrated that retention of visual images in WM was largely unaffected by the concurrent perceptual activation of visual representations in LTM. In contrast, the top-down activation of visual representations in LTM required in visual imagery *was* disrupted by a concurrent visual perception task. These findings are consistent with the workspace model in which visual images are assumed to be maintained in the WM system independently of the perceptually driven activation of representations in LTM. Imagery, on the other hand, involves the process of visual image generation, which competes with perceptual input for the limited resource that is required to activate representations in LTM. The neuropsychology experiment has provided evidence to suggest that under certain conditions, the activation of LTM can be dissociated from the conscious representation of stimuli in visual WM. This again, is consistent with the workspace view of WM as a system that is functionally separate from the perceptual system. Results from cognitive psychology thus converge with results from neuropsychology to support the workspace model of the interaction between WM and LTM. The dual-task experiments furthermore contribute importantly to the current debate on the theoretical interpretation of the selective interference effects of irrelevant visual input on visual imagery.

The interaction between working memory and long-term memory is a very important issue, at the core of understanding human memory and perception in particular, and healthy human cognition in general. The further systematic experimental investigation of the different models of the interaction between working memory and long-term memory, along the lines suggested throughout the present chapter, is thus vital. The focus in this thesis was on visual working memory and perception. Another way of continuing to explore the current issues would thus be by contributing to these findings with converging findings in the verbal domain.

In sum, even though the present data cannot be taken as conclusive proof for the workspace model, they do provide compelling evidence for its proposed functional separation of working memory processes and perceptual and long-term memory processes. No previous studies have made an attempt to differentiate and directly compare models of the interaction between working memory and long-term memory, and as such, the present thesis has provided a basis for the further empirical investigation of this important area of research.

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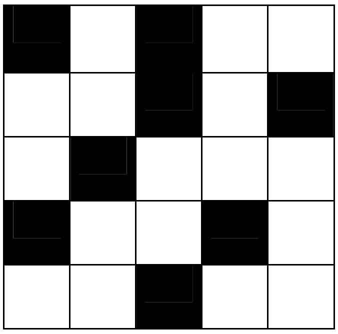
APPENDIX A

Patterns used in the Visual Patterns Task (Exp 1, 2, 3)

1.



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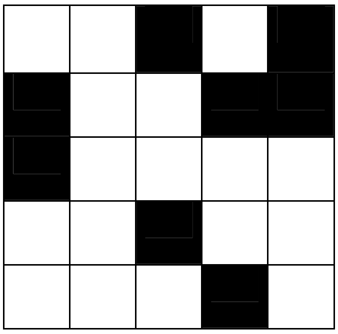

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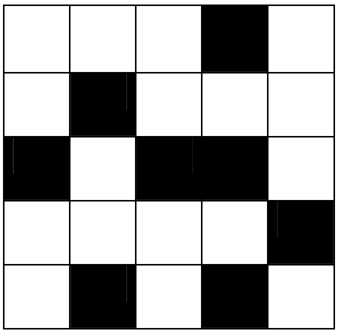

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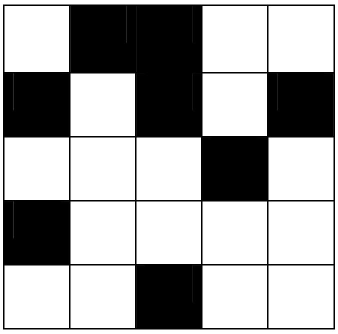

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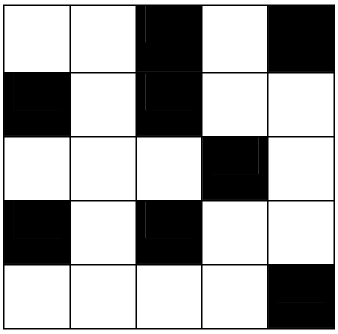

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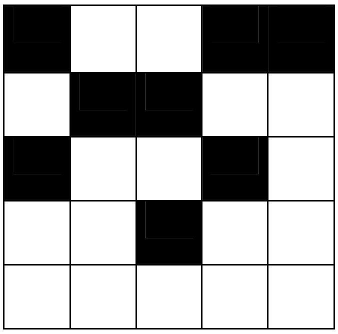

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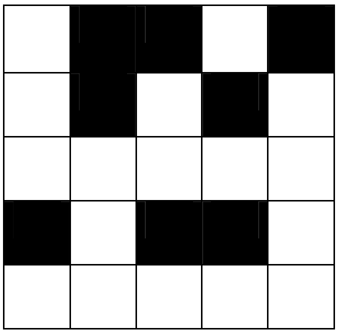

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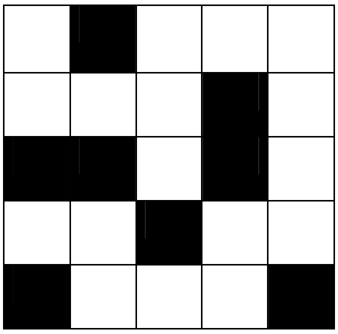

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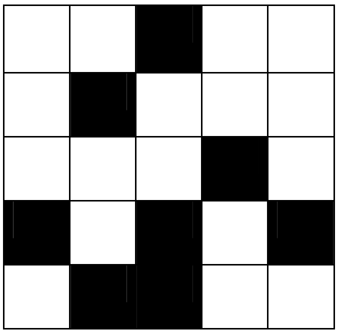

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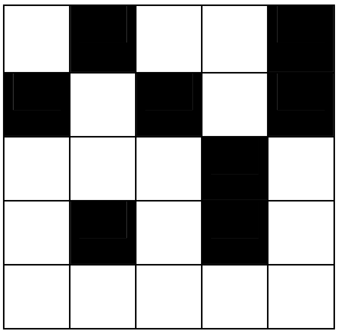

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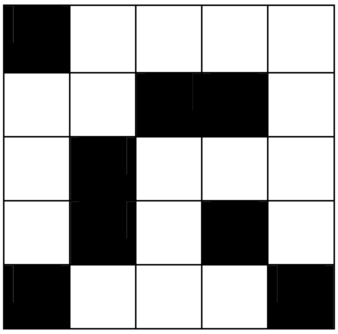

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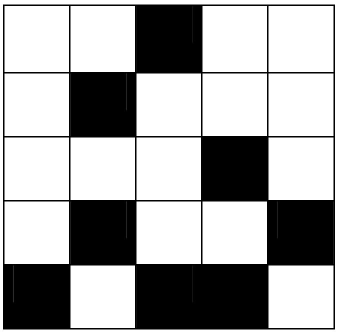

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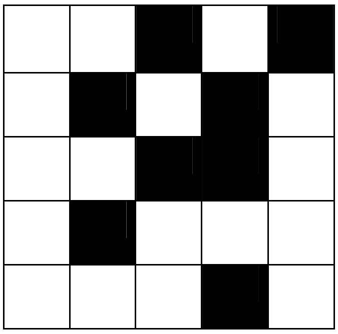

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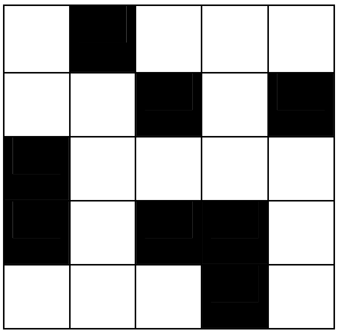

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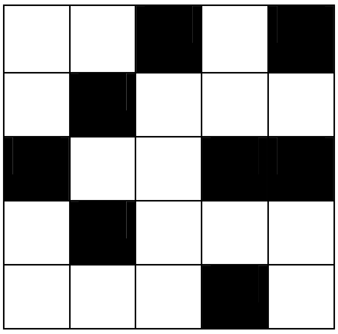

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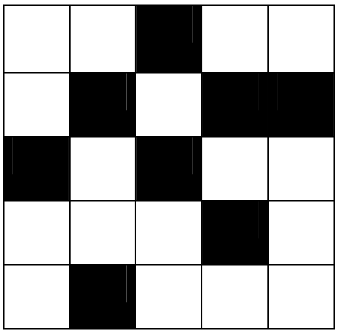

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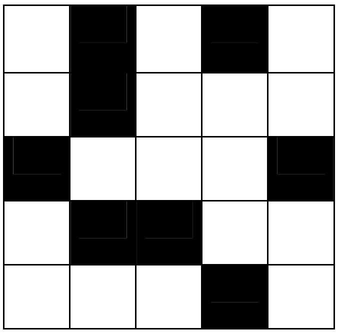

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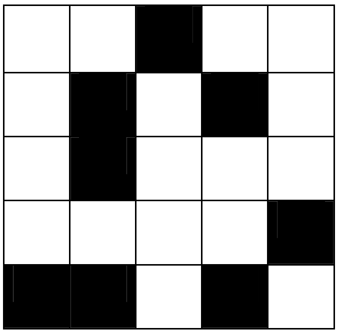

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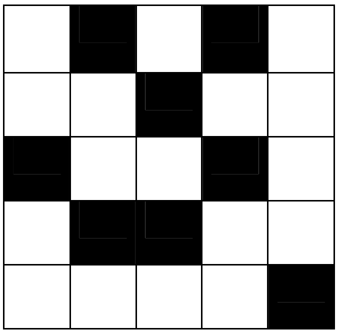

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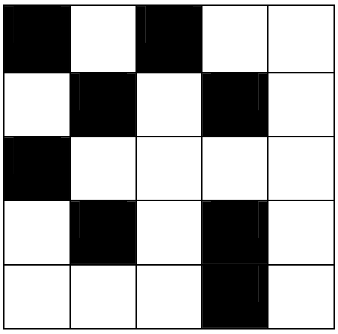


APPENDIX B

Names of pictures used in Experiment 1

Names are given in alphabetical order, with other accepted responses given in brackets.

Airplane (plane)
Alligator (crocodile)
Anchor
Apple
Ashtray
Baby carriage (pram)
Balloon
Banana
Barrel
Basket (box)
Bat
Bear (polar bear)
Bed
Beetle (insect/ bug)
Bell
Bicycle (bike)
Bird
Blouse (shirt)
Boot
Bottle
Bow
Bread
Broom
Brush
Bus
Butterfly
Button
Cake
Camel
Candle
Canon
Car
Carrot
Cat
Chair
Chicken (hen)
Church
Cigarette
Clock
Clothespin (clothes peg/ peg)
Clown
Coat (jacket)
Corn (corn on the cob)
Couch (sofa/ bench)
Cow
Crown
Cup
Deer (rein deer)
Desk
Dog
Doll
Doorknob
Dress
Dresser (set of drawers/ commode)
Drum
Duck
Eagle (bird of prey)
Ear
Elephant
Envelope (letter)

Eye
Fence
Fish
Flag
Flower
Fly (insect/ bug)
Foot
Football helmet (rugby helmet/ helmet)
Fork
Fox
Frying pan (pan)
Garbage bin (rubbish bin/ bin/ bucket)
Giraffe
Glass
Glasses
Glove
Grapes
Grasshopper
Guitar
Gun (pistol)
Hammer
Hand
Hanger (clothes hanger)
Harp
Hat
Helicopter
Horse
Iron
Iron board
Kangaroo
Kettle
Key
Kite
Lamp
Leaf
Light bulb (bulb)
Lion
Lobster
Lock
Mitten
Monkey
Moon
Motorcycle (motorbike)
Mouse (rat)
Mushroom
Nose
Nut
Onion
Ostrich
Owl
Paintbrush
Pan (sauce pan)
Pants (trousers)
Peacock
Peanut
Pear
Penguin
Piano (grand piano)
Pig
Pineapple
Pipe
Pitch (jug)
Pliers (spanner)
Plug
Rabbit (bunny)
Refrigerator (fridge)
Rhinoceros (rhino)
Rocking chair
Roller skate
Rolling pin

Rooster (cockerel/ cock)
Sailboat (boat)
Saltshaker (salt dispenser)
Sandwich
Saw
Scissors
Screw
Screwdriver
Sea horse
Seal (walrus)
Sheep (lamb)
Shoe
Sled (sledge)
Snail
Snake
Snowman
Spider (insect)
Spinning top (top)
Spinning wheel
Spool of thread (spool)
Spoon
Squirrel
Stool
Stove (cooker/ hob/ oven)
Strawberry
Suitcase
Sun
Swan
Table
Telephone (phone)
Television (t.v./ telly)
Tennis racket (racket)
Thimble
Tie
Tiger (cat/ leopard)
Toaster
Traffic lights (stop lights)
Train
Tree
Truck (lorry)
Trumpet
Turtle
Umbrella
Vase
Watch
Watering can
Well
Whistle
Windmill
Wine glass (glass)

APPENDIX C

Correct answers for the Letter Imaging Task (Exp 3, 4, 5, 6)

Criteria: ESA = enclosed spatial areas, LRS = left-right symmetry, ULS = upper-lower symmetry, SUL = similar upper/lower case, PLL = parallel lines, RNS = rounded shapes, RAN = right angles, SLN = single line, STL = straight lines

	ESA	LRS	ULS	SUL	PLL	RNS	RAN	SLN	STL
A	yes	yes	no	no	no	no	no	no	yes
B	yes	no	yes	no	yes	yes	yes	no	yes
C	no	no	yes	yes	no	yes	no	yes	no
D	yes	no	yes	no	no	yes	yes	no	yes
E	no	no	yes	no	yes	no	yes	no	yes
F	no	no	no	yes	yes	no	yes	no	yes
G	no	no	no	no	no	yes	yes	yes	yes
H	no	yes	yes	no	yes	no	yes	no	yes
I	no	yes	yes	yes	no	no	no	yes	yes
J	no	no	no	yes	no	yes	no	yes	no
K	no	no	no	yes	no	no	no	no	yes
L	no	no	no	no	no	no	yes	yes	yes
M	no	yes	no	yes	yes	no	no	yes	yes
N	no	no	no	no	yes	no	no	yes	yes
O	yes	yes	yes	yes	no	yes	no	yes	no
P	yes	no	no	yes	no	yes	yes	no	yes
Q	yes	no	no	no	no	yes	no	no	no
R	yes	no	no	no	no	yes	yes	no	yes
S	no	no	no	yes	no	yes	no	yes	no
T	no	yes	no	no	no	no	yes	no	yes
U	no	yes	no	yes	no	yes	no	yes	no
V	no	yes	no	yes	no	no	no	yes	yes
W	no	yes	no	yes	yes	no	no	yes	yes
X	no	yes	yes	yes	no	no	yes	no	yes
Y	no	yes	no	no	no	no	no	no	yes
Z	no	no	no	yes	yes	no	no	yes	yes

APPENDIX D

Stimuli used in the Letter Retention Task (Exp 4, 5, 6)

M r d Q
r q h L
h m L d
L q H r
q D l m
D H Q m
H q m r
R d l M
m h Q D
Q L M r
l D r q
D r M l

m Q h L
M q R H
d L q r
l h q m
r Q M d
H d l Q
q l R M
h D M q
R H q m
L d M H
Q h D R
r m H l

H r D l
m R H l
d q r H
M l D h
q M d h
D M L h
Q r m H
h l R M
R L D q
L r D M
d R m Q
l Q d h

APPENDIX E

Stimuli used in the Letter Retention Task (Exp 7)

List 1

D N R q h
N Q h d R
R d Q H n
Q r D h N
h N d R Q
D q H n R
n R Q D h
q H N R d
R D n H q
d n R q H
q n h D r
n h d r Q
H r N Q d
r Q D n H
h d r N q
d H q r N
Q D n h r
H q r N D

List 2

H Q d r N
h q N D R
Q h d R n
D n R H Q
N h r Q d
H r D N q
h q N D r
Q d R n H
q N H d R
n D h Q r
d R Q h N
n H q r D
d R Q n h
r N D H q
R n h q D
N H q r d
r D n q h
R Q n d H

List 3

d Q R n H
H d Q N r
q r D H n
d R H n q
h r N q D
D H n Q r
R Q d h N
h D n Q R
N d R h Q
q n D R h
Q h r d N
H N q R d
D R h N q
n q H r d
r H q D n
n q h r D
Q N r d H
R h N D Q

APPENDIX F

Pictorial stimuli used in Experiment 8

Pictures for familiar proverbs

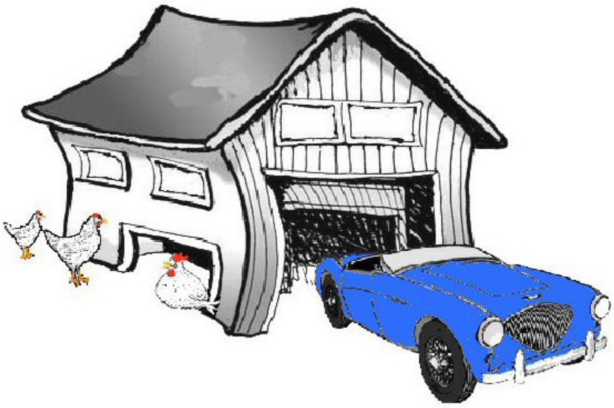
1. An apple a day keeps the doctor away

2. One bird in the hand is better than two in the bush

3. Kill two birds with one stone

4. You can't judge a book by its cover

5. The chickens have come home to roost



6. Don't count your chickens before they are hatched

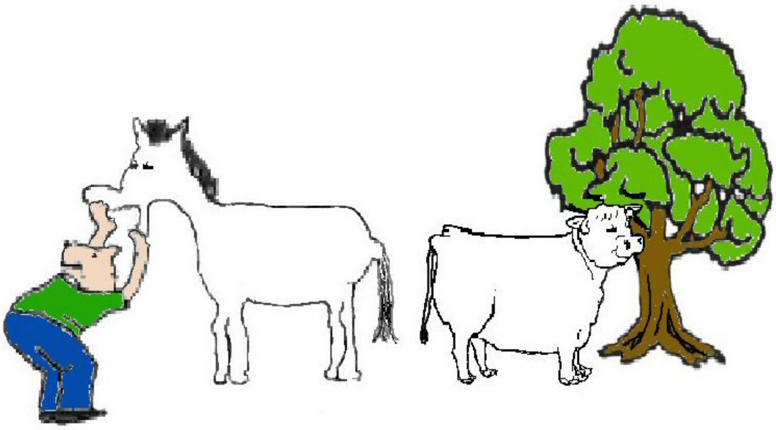
7. Don't put all your eggs in one basket

8. Make hay while the sun shines

9. Two heads are better than one

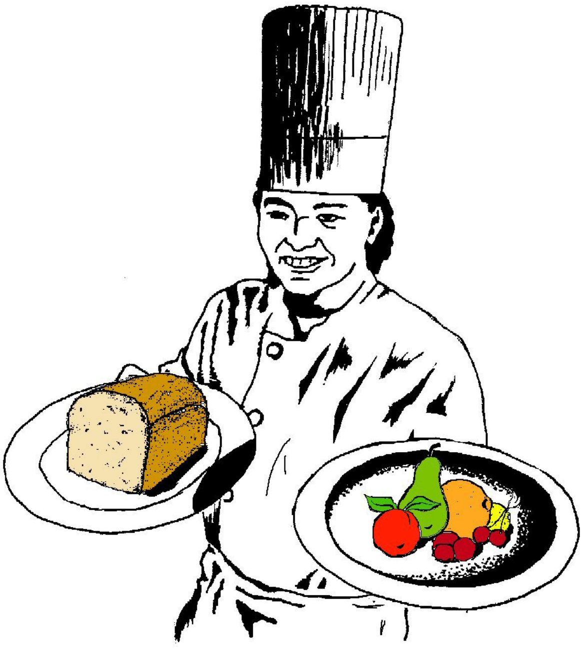
10. Home is where you hang your hat

11. Never look a gift horse in the mouth

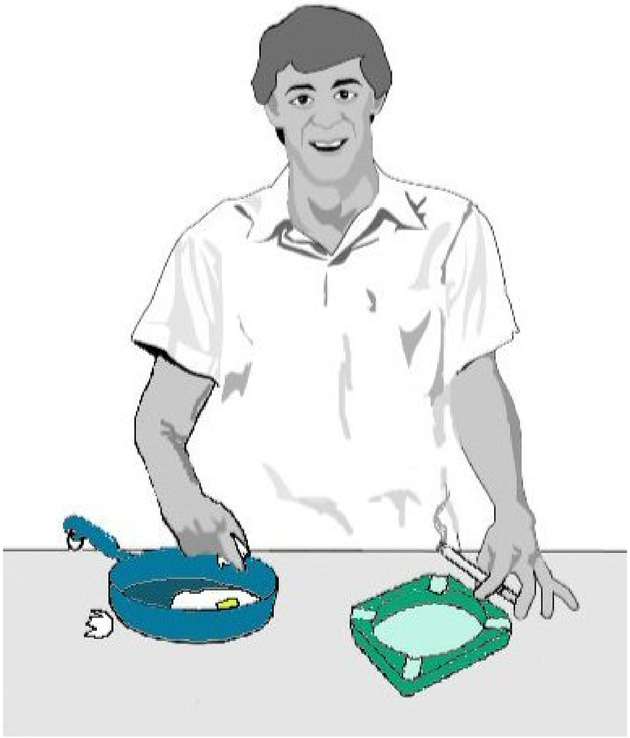


12. There are more ways of killing a cat than by choking it with cream

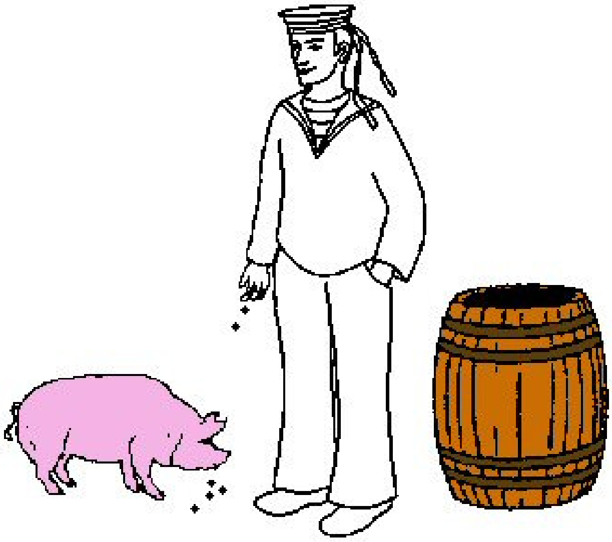
13. Half a loaf is better than none



14. You can't make an omelette without breaking eggs



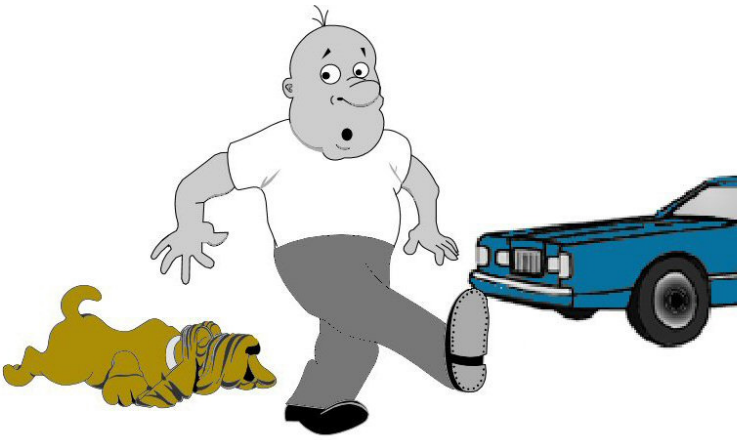
15. Don't cast your pearls before the swine



16. Give a man enough rope and he'll hang himself

17. You can't run with the hare and hunt with the hounds

18. Let sleeping dogs lie



19. You can't squeeze blood from a stone

20. The pen is mightier than the sword

Pictures of unfamiliar proverbs

1. Don’t throw ashes in the food

2. Never lay down the axe

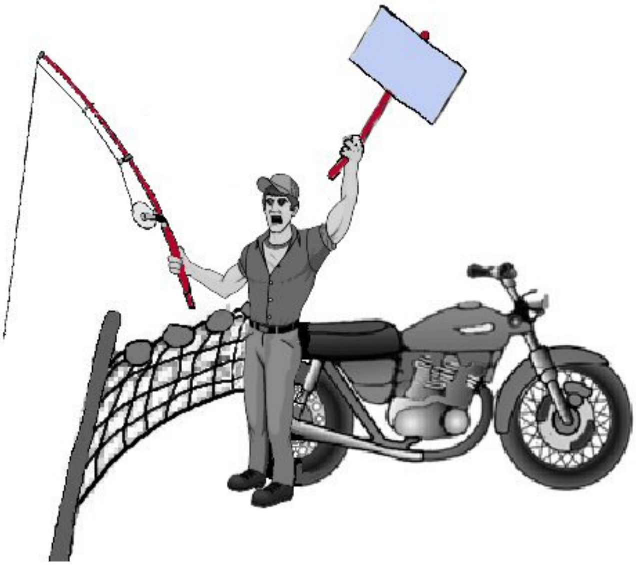
3. Don’t carry water to the sea

4. Don’t buy a cat in a bag

5. Don’t let anyone eat the cheese from your bread

6. Not only cooks hold long knives

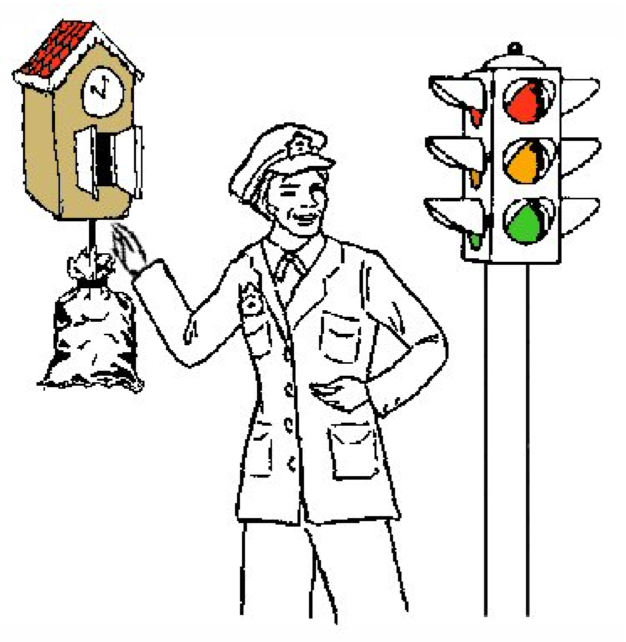
7. Don’t fish behind the net



8. Don’t always hammer on the same anvil

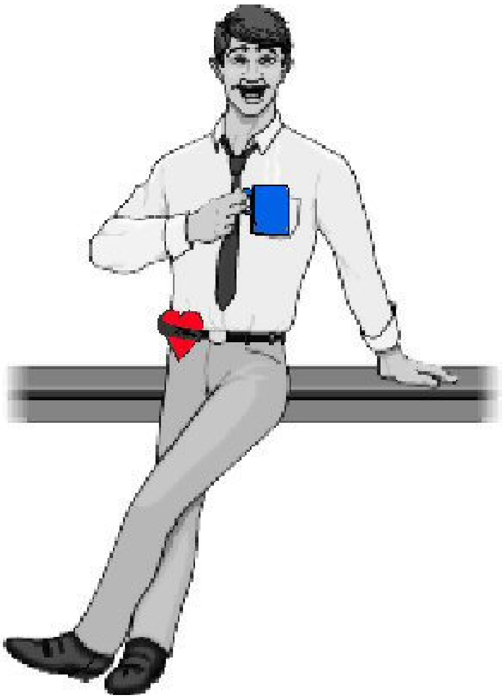
9. When one hand washes the other, they both get clean

10. Don’t hang anything on the large clock

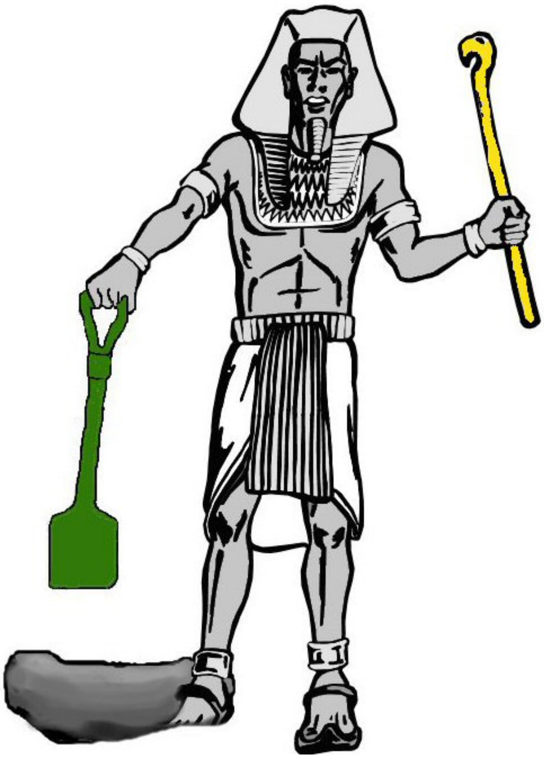


11. With the hat in the hand, you can travel around the entire country

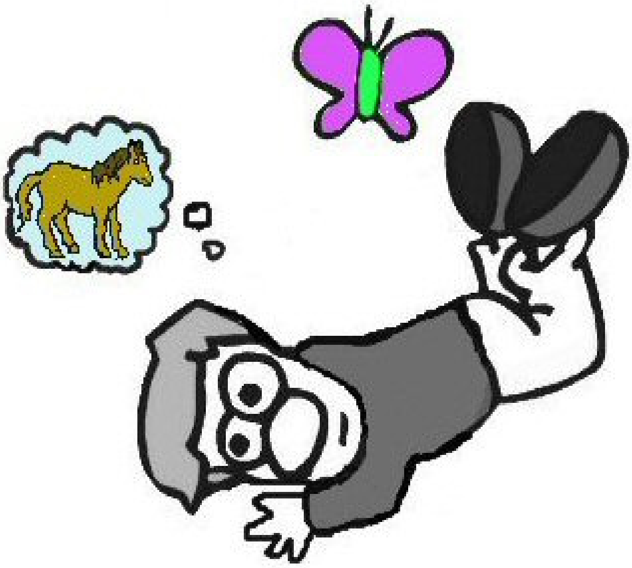
12. Stick a heart under a person’s belt



13. He who digs a hole for another, falls in it himself



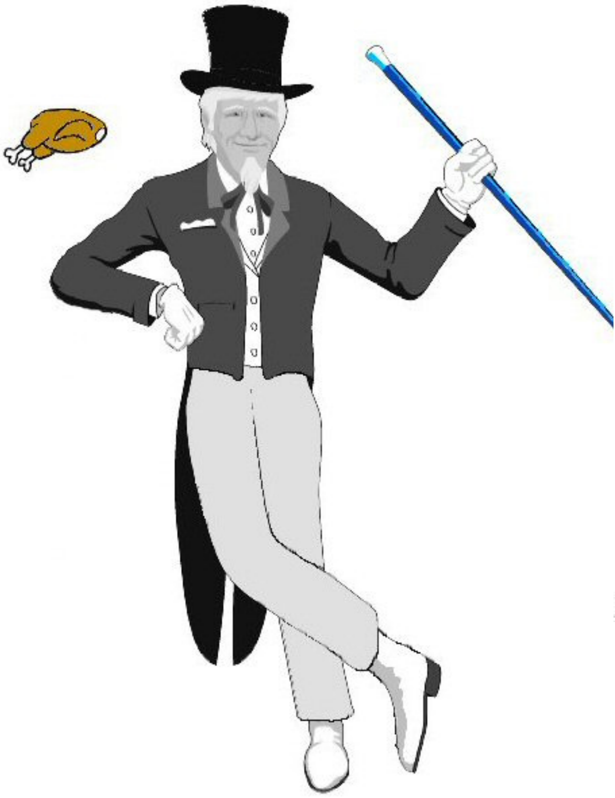
14. When you hear hoof beats, think horses, not zebras



15. Don’t bring a leaf in front of your mouth

16. It is good to have a person on your hand

17. The roasted pigeons don’t fly into your mouth



18. The soup is spilled between spoon and mouth

19. The pitcher goes so often to the well that it comes home broken at last

20. Don’t squeeze the cat in the dark

APPENDIX G

Proverb sets used in Experiment 8

The order of proverb sets in this list corresponds with the order of the pictorial stimuli given in Appendix F. Proverbs within each group of four are given in the order in which they were presented on audio files in Experiment 8. **Bold** proverbs are the target proverbs, *italic* proverbs are the foils.

Familiar proverbs

1. One man’s loss is another man’s gain
   One rotten apple spoils the barrel
   An apple a day keeps the doctor away
   A man is known by his friends

2. **A bird in the hand is worth two in the bush**
   Old habits die hard
   Birds of one feather flock together
   It takes two to tango

3. *Those who live in glass houses shouldn't throw stones*
   A bad penny always turns up
   A penny saved is a penny earned
   Kill two birds with one stone

4. **You can’t judge a book by its cover**
   Better late than never
   A good book is the best of friends
   Prevention is better than cure

5. *Which came first: the chicken or the egg?*
   You can't make a silk purse from a sow's ear
   Experience is the best teacher
   The chickens have come home to roost

6. *You can't teach grandma to suck eggs*

   Don’t count your chickens before they are hatched

   He who laughs last, laughs best

   He who pays the piper calls the tune

7. Still waters run deep

   Blood is thicker than water

   Walking on egg shells

   Don’t put all your eggs in one basket

8. Easier said than done

   Looking for a needle in a hay stack

   A fool and his money are easily parted

   Make hay while the sun shines

9. **Two heads are better than one**

   Every cloud has a silver lining

   Heavy is the head that wears the crown

   A rolling stone gathers no moss

10. **Home is where you hang your hat**

    Empty barrels make the most sound

    If the cap fits, wear it

    Little strokes fell oaks

11. A woman’s work is never done

    All lay loads on a willing horse

    Never look a gift horse in the mouth

    If the shoe fits, wear it

12. A man is known by the company he keeps

    There are more ways of killing a cat than by choking it with cream

    Clothes make the man

    A cat may look at a king

13. *Bread is the stuff of life*
    Rats desert a sinking ship
    Half a loaf is better than none
    Don't cry over spilt milk

14. *A watched pot never boils*
    Why have a dog and bark yourself
    Hair of the dog that bit you
    You can’t make an omelette without breaking eggs

15. **Don’t cast your pearls before swine**
    Better to light a candle than to curse the darkness
    Don't hide your light under a bushel
    The worst pig often gets the best pear

16. Paddle your own canoe
    Give a man enough rope and he’ll hang himself
    Up a creek without a paddle
    Give a dog a bad name and hang him

17. *Learn to walk before you run*
    When the cat is away, the mice will play
    You can’t run with the hare and hunt with the hounds
    Curiosity killed the cat

18. A picture says a thousand words
    Let sleeping dogs lie
    Actions speak louder than words
    A dog is a man’s best friend

19. Don’t make a mountain out of a molehill
    You can’t squeeze blood from a stone
    Faith will move mountains
    Let he who is without sin cast the first stone

20. **The pen is mightier than the sword**
The leopard cannot change its spots
He who lives by the sword shall die by the sword
Out of sight, out of mind

Unfamiliar proverbs

1. Don’t make a long nose
Don’t throw ashes in the food
Always have something to crumble in the milk
Don’t put a pen on anyone’s nose

2. Don't open a book of someone else
Half an egg is better than an empty shell
Never lay down the axe
Don't use an axe to cut a thread

3. **Don’t carry water to the sea**
Save an apple for the thirst
Bite through the sour apple
Don't drown before having seen any water

4. Rowing goes well beneath an open sail
Don’t buy a cat in a bag
Always keep an eye on the sail
First watch the cat out of the tree

5. **Don’t let anyone eat the cheese from your bread**
Don't shoot a goat
A prophet who eats bread
Sitting on something like the goat on a box with oats

6. **Not only cooks hold long knives**

   Hearing the bells ringing but not knowing where the clapper hangs

   Don't be sent with a clod into the reed

   The one knife keeps the other in the sheath

7. Don’t make an elephant out of a mosquito

   Don’t use a cannon to shoot a mosquito

   Everyone fishes on their tide

   Don’t fish behind the net

8. Even if a monkey wears a golden ring, it is and remains an ugly thing

   Don’t always hammer on the same anvil

   A silver hammer breaks iron doors

   The monkey comes out of the sleeve

9. All cats love fish but hate to get their paws wet

   When one hand washes the other, they both get clean

   For the cat’s violin

   Two hands on one belly

10. *The clock ticks nowhere the way it does at home*

    Don't jump from the ox to the donkey

    Don’t hang anything on the large clock

    Jump in the corner for someone else

11. Don't lift a person over the horse

    With the hat in the hand you can travel around the entire country

    No horse is called piebald when there is no spot on it

    Never throw the hat at a job

12. *Only the heart without a stain knows perfect ease*

    Don’t lay your head in your lap

    Stick a heart under a person’s belt

    Don't come home with a stocking on your head

13. It is difficult catching hares with unwilling dogs
    He who digs a hole for another, falls in it himself
    Don't dig old cows out of the creek
    Over the dog, over the tail

14. *Good horses are in the stable, birds are everywhere*
    The musician is still on the roof
    Every path has its puddle
    When you hear hoof beats, think horses, not zebras

15. **Don’t bring a leaf in front of your mouth**
    Don’t stand there with your mouth full of teeth
    Don't sit with your hands in your hair
    Don’t sit down besides the boxes

16. When the calf is drowned…
    It is good to have a person on your hand
    Always keep something behind the hand
    Why pay for the cow when the milk is free

17. **The roasted pigeons don’t fly into your mouth**
    Every bird sings as it is beaked
    Laughing like a farmer with a toothache
    Some have two left hands

18. Don’t shake things out of your sleeve
    The soup is not worth the vegetables
    The soup is spilled between spoon and mouth
    Don't pin something on a person's sleeve

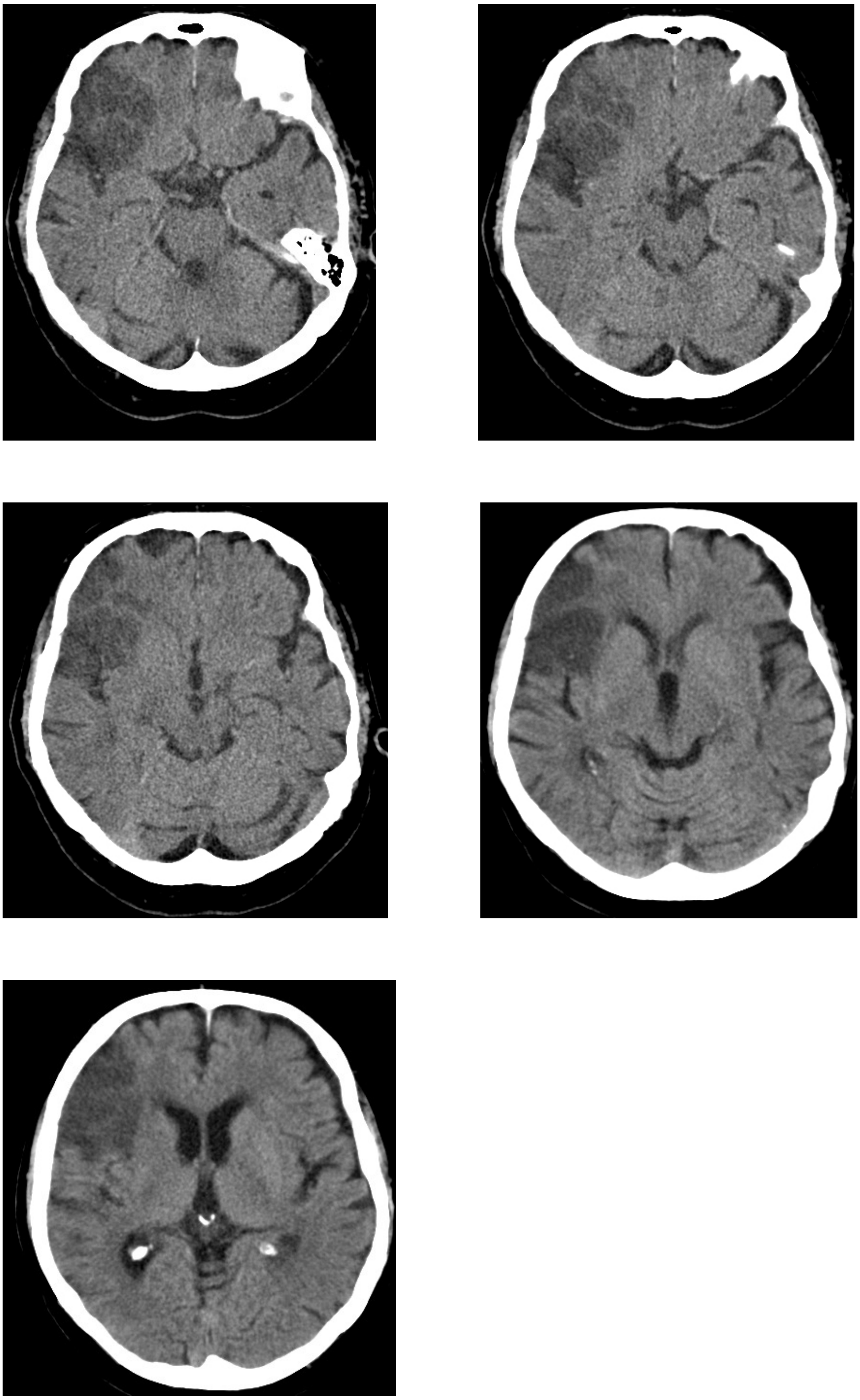
19. Don’t pull the sheet through the eye of the scissors
    The pitcher goes so often to the well that it comes home broken at last
    He who wants to have the last from the jug, gets the lid on the nose
    From the rain into the drip

20. Only strong legs can carry the luxury
    Feeling like a cat in a strange warehouse
    A clog on the leg
    Don’t squeeze the cat in the dark

APPENDIX H

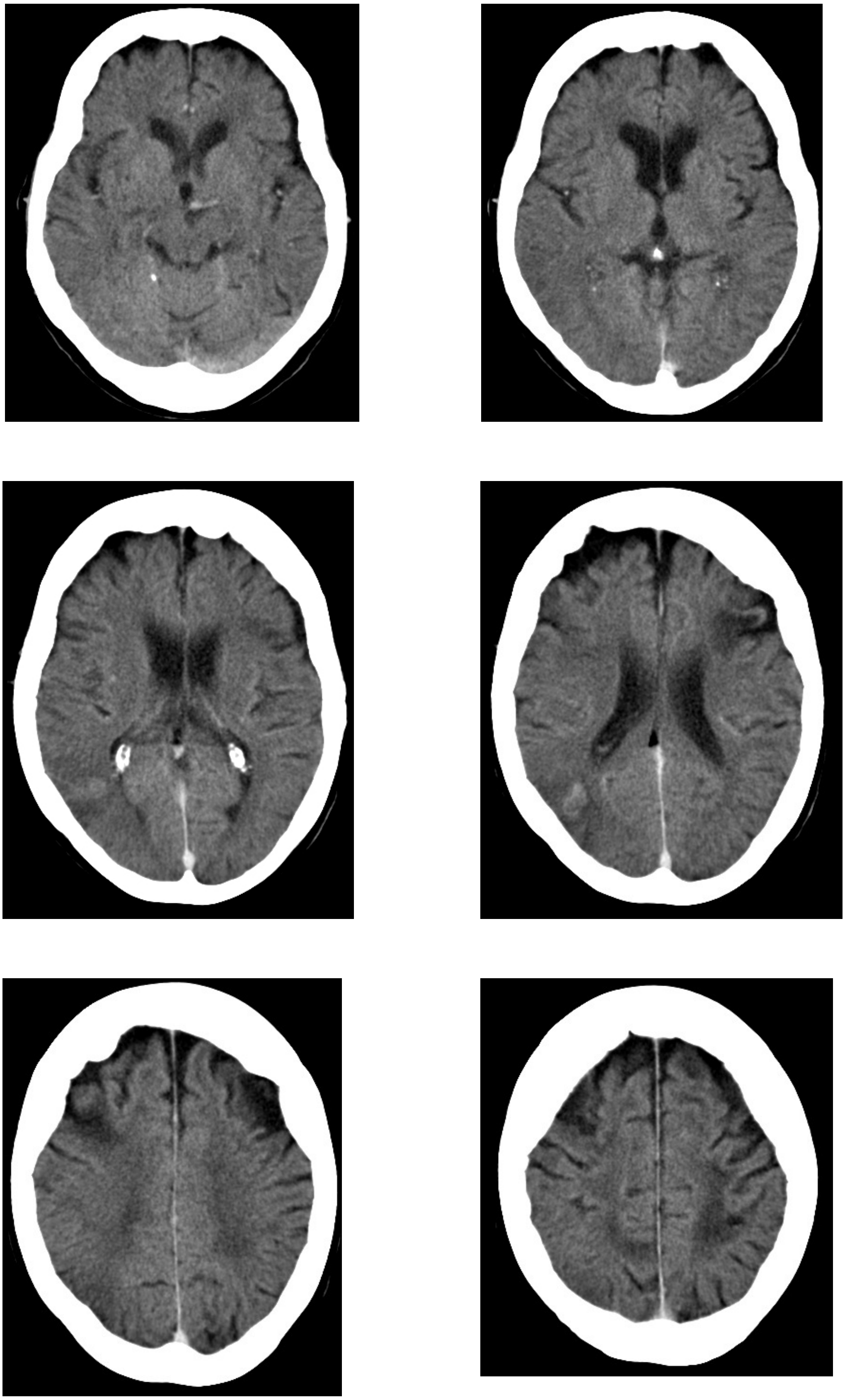
CT scans of patients of Experiment 8

Patient CK (Male, 78, right-sided fronto-temporal infarct)

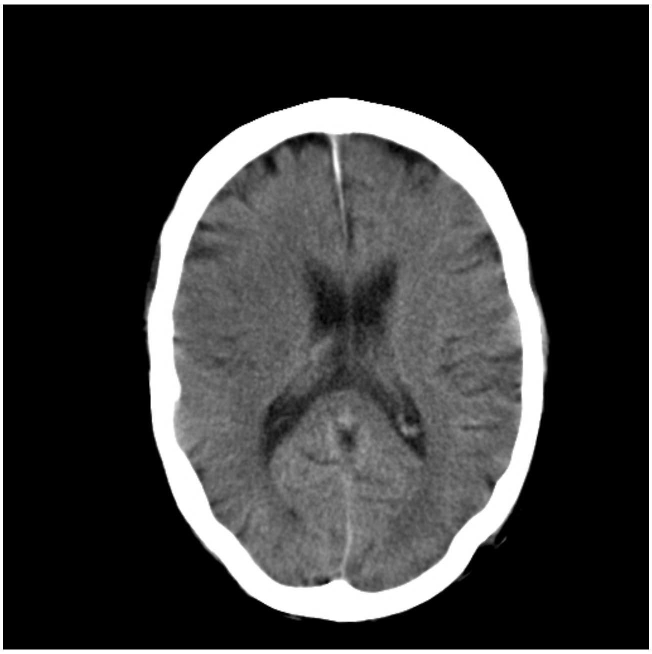


Patient EW (Male, 72, large right middle single cerebral artery territory infarct)

Patient JL (Female, 78, right-sided inferior posterior parietal haemorrhage)



Patient PM (Male, 61, right-sided total anterior circulation stroke)



APPENDIX I

Statistical Tables

Experiment 1

Within-subjects ANOVA on performance on the visual patterns task in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Recall	1	5.695	35	.43	13.253	.001

One-way ANOVA on performance levels in three trial groups in both conditions of the visual patterns task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Single-task	2	7.245	70	.552	13.124	.000
Dual-task	2	1.803	70	1.297	1.390	.256

Within-subjects ANOVA on picture naming performance (proportion correct names) in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Proportion correct names	1	3.511	35	.342	10.265	.003
Reaction time	1	20514.621	32	1544.158	13.285	.001

Between-subjects ANOVAs testing the effect of presentation order of two single-task conditions on measures of performance on the visual patterns task and picture naming

	df	MS	F	p-level
Visual patterns task – single	1	.093	.122	.729
Visual patterns task – dual	1	.834	1.019	.320
Picture naming (recall) – single	1	.179	.414	.524
Picture naming (recall) – dual	1	.118	.171	.682
Picture naming (RT) – single	1	4214.087	.706	.407
Picture naming (RT) – dual	1	7521.014	2.357	.135

Experiment 2

Within-subjects ANOVA on performance on the visual patterns task in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Recall	1	12.038	35	.318	37.802	.000

One-way ANOVA on performance levels in three trial groups in both conditions of the visual patterns task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Single-task	2	3.158	70	.781	4.044	.022
Dual-task	2	2.951	70	.847	3.486	.036

Within-subjects ANOVA on tapping performance in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Mean speed	1	.0455	35	.00151	30.191	.000
Constancy of speed	1	.000613	35	.000221	2.771	.105

Between-subjects ANOVAs testing the effect of presentation order of two single-task conditions on measures of performance on the visual patterns task and tapping

	df	MS	F	p-level
Visual patterns task – single	1	.550	.944	.338
Visual patterns task – dual	1	.370	.379	.542
Tapping (speed) – single	1	.002	.694	.411
Tapping (speed) – dual	1	.006	.951	.336
Tapping (constancy) – single	1	.000	.064	.801
Tapping (constancy) – dual	1	.000	.028	.868

Two-way ANOVA comparing the effects of picture naming and tapping on performance of the visual patterns task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	17.147	70	.374	45.835	.000
Interference type	1	.00918	70	1.177	.008	.930
Interaction	1	.587	70		1.568	.215

Experiment 3

Within-subjects ANOVA on performance on the visual patterns task in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Recall	1	17.444	35	.351	49.768	.000

One-way ANOVA on performance levels in three trial groups in both conditions of the visual patterns task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Single-task	2	5.833	70	.590	9.886	.000
Dual-task	2	1.038	70	1.018	1.020	.366

Within-subjects ANOVA on performance on the letter imaging task in single- and dual-task condition

	df Effect	MS Effect	df Error	MS Error	F	p-level
Correct responses	1	1.194	35	.350	3.413	.073

Two-way ANOVA comparing the effects of picture naming and letter imaging on performance of the visual patterns task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	21.537	70	.390	55.206	.000
Interference type	1	.173	70	1.085	.159	.691
Interaction	1	1.602	70		4.107	.047

Experiment 4

Repeated measures ANOVA on the effects of DVN on the retention and generation task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.352	31	.252	1.397	.246
Main task	1	1652.909	31	1.411	1171.364	.000
Interaction	1	.540	31	.334	1.613	.213

Within-subjects ANOVAs on performance in control and interference conditions of the retention and generation task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Retention	1	.01	31	.237	.042	.839
Generation	1	.881	31	.349	2.524	.122

Two-way ANOVA on retention task performance to test the influence of presentation order of conditions

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.01	30	.159	.063	.804
Order	1	1.020	30	.750	1.360	.253
Interaction	1	2.568			16.121	.000

Two-way ANOVA on generation task performance to test the influence of presentation order of conditions

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.881	30	.284	3.103	.088
Order	1	.277	30	2.631	.105	.748
Interaction	1	2.307			8.123	.008

Repeated-measures ANOVAs for performance on the retention and generation task over different trial groups, to test for a learning effect

	df Effect	MS Effect	df Error	MS Error	F	p-level
Retention	5	2.257	155	.336	6.709	.000
Generation	5	5.131	155	1.350	3.800	.003

Experiment 5

Repeated measures ANOVA on the effects of pictures on the retention and generation task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	6.391	23	.306	20.872	.000
Main task	1	1398.503	23	1.252	1117.307	.000
Interaction	1	3.485	23	.564	6.177	.021

Two-way ANOVA on retention task performance to test the influence of presentation order of conditions

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.219	22	.115	1.895	.183
Order	1	.001	22	.814	.001	.970
Interaction	1	3.403			29.481	.000

Two-way ANOVA on generation task performance to test the influence of presentation order of conditions

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	9.657	22	.632	15.274	.001
Order	1	1.317	22	1.441	.914	.350
Interaction	1	.167			.264	.613

Two-way ANOVA comparing effects of DVN and pictures on retention task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.083	54	.246	.337	.564
Exp	1	.055	54	.768	.072	.789
Interaction	1	.176			.713	.402

Two-way ANOVA comparing effects of DVN and pictures on generation task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	8.783	54	.461	19.047	.000
Exp	1	4.424	54	2.079	2.128	.150
Interaction	1	3.009			6.524	.013

Experiment 6

Repeated measures ANOVA on the effects of tapping on the retention and generation task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	.994	23	.214	4.652	.042
Main task	1	1252.020	23	1.092	1146.030	.000
Interaction	1	1.879	23	.271	6.940	.015

One-way ANOVAs testing the effect of tapping on different retention task recall variables

	df Effect	**MS Effect**	**df Error**	**MS Error**	**F**	**p-level**
Case (C)	1	1.404	23	.056	25.211	.000
Identity (I)	1	.314	23	.032	9.850	.005
Serial order	1	1.169	23	.278	4.201	.052
C + I	1	2.121	23	.093	22.727	.000

One-way ANOVAs on tapping data

	df Effect	**MS Effect**	**df Error**	**MS Error**	**F**	**p-level**
Errors	1	38.521	23	40.912	.942	.342
Speed	1	.035	23	.015	2.417	.134
Constancy	1	.005	23	.001	4.952	.036

Three-way ANOVA comparing the effects of pictures and tapping on the two main tasks

	df Effect	**MS Effect**	**df Error**	**MS Error**	**F**	**p-level**
Condition (C)	1	6.214	46	.260	23.902	.000
Task (T)	1	2648.498	46	1.172	2259.659	.000
Exp (E)	1	7.223	46	1.214	5.952	.019
C * T	1	.123	46	.417	.295	.590
C * E	1	1.172			4.508	.039
T * E	1	2.025			1.728	.195
C * T * E	1	5.240			12.554	.001

Experiment 7

One-way ANOVAs testing the effects of the two types of tapping on different retention task recall variables

	df Effect	MS Effect	df Error	MS Error	F	p-level
Case (C)	2	3.424	34	.201	17.003	.000
Serial order (S)	2	5.041	34	.400	12.591	.000
C + I	2	4.377	34	.165	26.574	.000
C + I + S	2	8.727	34	.361	24.165	.000

Repeated measures ANOVA investigating the effects of the Figure-of-eight tapping task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	3.690	17	.381	9.685	.006
Recall variable	3	1.729	51	.065	26.682	.000
Interaction	3	.328	51	.030	10.817	.000

Repeated measures ANOVA investigating the effects of the Syncopated tapping task

	df Effect	MS Effect	df Error	MS Error	F	p-level
Condition	1	38.678	17	1.321	29.284	.000
Recall variable	3	2.421	51	.114	21.270	.000
Interaction	3	.436	51	.095	4.580	.006

Experiment 8

Paired-samples t-tests on target responses of pilot participants on familiar and unfamiliar trials, for left halves and right halves of pictures

	Mean	St. Dev.	St. Er. M	t	df	p-level
Left halves	.200	2.29976	.72725	.275	9	.790
Right halves	-.300	1.56702	.49554	-.605	9	.560

Between-subjects ANOVA on target proportions on aware mirror trials of CK, control patients and healthy controls

	df between	**MS between**	**df within**	**MS within**	**F**	**p-level**
Participants	2	.008	16	.016	.504	.613

Between-subjects ANOVAs on target proportions on aware trials of CK, control patients and healthy controls, for familiar and unfamiliar trials

	df between	**MS between**	**df within**	**MS within**	**F**	**p-level**
Familiar	2	.007	16	.007	1.048	.374
Unfamiliar	2	.004	16	.007	.662	.529