Effects of Age on Implicit Memory

Implications for Single and Multiple-Systems Theories

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Declaration

I declare that the work presented in this thesis is a product of my own efforts. Data collection in Experiments 5, 8, 9 and 10 was partly assisted by UCL BSc and MSc project students. Experiments 1, 2, 3, 7, 8 and 9 appear in the paper: Ward, E. V., Berry, C. J., & Shanks, D. R. (in press). An effect of age on implicit memory that is not due to explicit contamination: Implications for single and multiple-systems theories. *Psychology and Aging*.

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Abstract

Explicit memory declines with age, but research suggests that implicit memory may be preserved. For example, recognition memory is typically weaker in healthy older relative to young adults while performance on implicit tests such as perceptual identification is often comparable between groups (i.e., they show equivalent priming). Such observations are commonly taken as evidence for distinct explicit and implicit memory systems, but there are several concerns with this interpretation. One prominent issue is that dissociations between explicit and implicit memory may arise due to differences in the way in which the two are traditionally measured. In this thesis, I aimed to overcome some of the problems and provide a more robust test of a key multiple-systems prediction: that priming is preserved in old age despite reduced recognition memory. The two memory phenomena were measured concurrently trial-by-trial using the continuous identification with recognition (CID-R) task. In three experiments recognition was significantly reduced by age, and there was a reliable reduction in priming when the data were combined across experiments to increase statistical power.

It is often argued that age effects in priming reflect the use of explicit strategies which are more beneficial to young adults (‘explicit contamination’), so in a second stream of experiments I examined the contribution of test awareness and explicit processing to priming in young adults on the CID task. No evidence that priming is affected by these factors was produced, thus it is unlikely that young individuals were able to substantially boost their performance on this task in relation to older adults by using an explicit strategy. Collectively, the findings indicate that performance on implicit tests is not always age-invariant, and that the present age-related reduction in priming cannot be attributed to explicit contamination. The results are compatible with the view that a single system drives explicit and implicit memory phenomena.

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Chapter 1: Introduction

1.1 The organisation of memory: The explicit-implicit distinction

Human memory can be expressed in different ways. The conscious experience of remembering information or past encounters seems very different to the type of memory that allows us to ride a bicycle without giving much thought to the actions involved. The distinction between these *explicit* and *implicit* forms of memory has fuelled enormous debate regarding the structure and operations of memory, and a plethora of research spanning over three decades has attempted to determine whether or not they are driven by distinct cognitive systems. Formally, explicit (sometimes called declarative) memory can be defined as the conscious recollection of previous experiences, while implicit (sometimes called procedural) memory is evident when previous experiences affect (e.g., facilitate) performance on tasks that do not require conscious recollection of those experiences (Schacter, 1987).

In the laboratory, indices of explicit and implicit memory are captured using direct and indirect tests, respectively. Direct tests instruct participants to deliberately attempt to recall or recognise specific information from a prior episode. For example, in a recognition memory task, participants study a series of stimuli such as pictures or words and are later asked to discriminate between previously studied and new items. In contrast, indirect tests assess memory for previously studied information in a seemingly unrelated task, without reference to the prior study episode. Perceptual identification is a commonly used indirect task (e.g., Buchner & Wippich, 2000; Feustel, Shiffrin, & Salasoo, 1983; Jacoby & Dallas, 1981; Stark & McClelland, 2000). Here, previously studied (henceforth old) and new stimuli are presented either very briefly or in a degraded form at test, and participants are simply asked to identify them. Implicit memory is inferred by speeded or more accurate identifications of old relative to new items, a phenomenon known as repetition priming (henceforth priming).[1] Another commonly used implicit test is word-stem completion (e.g., Graf, Squire, & Mandler, 1984). Here, following an initial study phase in which a series of

[1] Throughout the thesis the terms *priming* and *implicit memory* are used interchangeably, as are the terms *direct* and *explicit* memory test, and *indirect* and *implicit* memory test.

words are presented (e.g., 'house', 'truck', etc), participants are asked to complete word-stems (e.g., ho___) with the first word that comes to mind. Priming is evident when the prior exposure increases the likelihood of completing stems with old relative to new items (e.g., 'house' rather than 'horse' in the example above).

If expressions of explicit and implicit memory reflect the operations of distinct systems, then one might expect experimental manipulations to produce qualitatively different effects on direct and indirect tests – functional dissociations. Such evidence is now abundant. For example, priming has been shown to occur on word-stem completion tasks even when participants are unable to explicitly retrieve the words from memory (e.g., Graf et al., 1984). However, the interpretation that this reflects the operations of distinct memory systems has raised a great deal of controversy. In the following subsections I review the evidence for multiple memory systems and introduce the single-system perspective, which argues that explicit and implicit forms of memory are driven by a unitary system.[2]

1.1.1 Evidence for multiple systems

The multiple-systems view states that explicit and implicit forms of memory are qualitatively distinct and driven by functionally independent systems. The systems are thought to divide on consciousness, operate freely of one another, and depend on different regions of the brain (e.g., Gabrieli, 1998; 1999; Schacter, 1987; Schacter & Tulving, 1994; Squire, 1994, 2004, 2009; Tulving & Schacter, 1990). Evidence for this account can be broken down into three main streams: (a) behavioural dissociations, (b) neuropsychological dissociations, and (c) neuroimageing evidence. Each stream of evidence will be reviewed in turn.

The simplest form of behavioural dissociation is when an experimental manipulation has an effect on one form of memory but not the other. Several factors have been identified which affect performance on explicit but not implicit tasks (reviewed in Roediger & McDermott, 1993). For example, deep (semantic) versus shallow (perceptual) processing at study affects subsequent explicit memory function, but usually has little or no effect on tests

[2] There are several different uses of the terms *explicit* and *implicit* memory, of which there is much overlap in the literature. This thesis is concerned with the question of whether these forms of memory are distinct in the sense that there are qualitatively independent hypothetical explicit and implicit memory systems, as defined by the multiple-systems account. In the context of the single-system perspective, we talk about explicit and implicit forms of memory as different *expressions* of memory on tasks that have different requirements (i.e., direct versus indirect instructions), and which are driven by a unitary hypothetical memory system.

of implicit memory (e.g., Jacoby & Dallas, 1981; Richardson-Klavehn & Gardiner, 1998), and delaying memory testing following study typically has a much greater detrimental effect on tests of explicit than implicit memory (e.g., Mitchell, 2006; Mitchell & Brown, 1988; Mitchell, Brown, & Murphy, 1990). Other factors have been identified which produce dissociations of a reversed nature – having an effect on implicit but not explicit memory. For example, priming is typically reduced for stimuli that are presented in a different modality at test than study (e.g., auditory to visual), while recognition is little affected (e.g., Craik, Moscovitch, & McDowd, 1994; Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987). These findings have been taken to suggest that the systems supporting explicit and implicit memory are independent and can be selectively influenced.

Other variables are capable of producing opposite effects on direct and indirect memory tests. Jacoby (1983a) asked participants to either read or generate words from antonyms at study, and subsequent performance on recognition and priming (perceptual identification) tests was compared. The magnitude of priming was greater for words that were read rather than generated, whereas the opposite was true of recognition memory. In another study, Voss and Gonsalves (2010) showed that manipulating the duration with which items are studied (brief versus long) differentially affects subsequent recognition and priming: Long study resulted in better recognition of items relative to brief study, while priming (speed of natural/manmade classifications) benefited more from brief relative to long study.

There is also evidence that priming can occur in the absence of explicit memory – that is, when recognition is not significantly above chance (e.g., Butler & Klein, 2009; Hamann & Squire, 1997a, 1997b; Kunst-Wilson & Zajonc, 1980; Merikle & Reingold, 1991; Mitchell et al. 1990; Stark & McClelland, 2000; Vuilleumier, Schwartz, Duhoux, Dolan, & Driver, 2005). In Vuilleumier et al.'s (2005) study, participants were exposed to pairs of overlapping line drawings of objects, one red and one blue, for 250 ms and instructed to attend to either the red or blue stream (rapid serial visual presentation procedure – RSVP). At test, participants performed either a recognition task or a fragmented picture identification task (priming measure) in which old and new objects were shown in a progressively less fragmented form until the item was correctly identified. Previously unattended items were identified at a greater level of fragmentation compared to new items (a priming effect), but recognition of unattended items did not exceed chance. In another study using a within-subjects design, Mitchell et al. (1990) found that priming in picture naming did not significantly differ for old items which were remembered (hits) versus those that were forgotten (misses), and this was taken as evidence for priming in the absence of explicit memory, and for the functional independence of explicit and implicit memory systems.

The second strand of evidence for multiple systems, and probably some of the most compelling, is that documenting neuropsychological dissociations. There is evidence that individuals with amnesia due to damage to the hippocampus or other regions within the medial temporal lobe exhibit a selective deficit in explicit memory function. These individuals, the most prominent probably being E.P., tend to perform very poorly on explicit tests such as recall and recognition, but often demonstrate priming levels equivalent to that in healthy controls (e.g., Conroy, Hopkins, & Squire, 2005; Graf et al., 1984; Hamman & Squire, 1997a; 1997b; Jacoby & Witherspoon, 1982; Stark & Squire, 2000; Warrington & Weiskrantz, 1970; 1974). A similar pattern is seen in normal ageing, which is examined in depth in section 1.2 of the Introduction. These findings go beyond simple behavioural dissociations as they suggest that different brain regions are responsible for explicit and implicit memory. While the hippocampus and medial temporal lobe appear to be crucial for explicit memory function, the right occipital lobe appears to play a key role in implicit memory – Gabrieli, Fleischman, Keane, Reminger, and Morrell (1995) reported a case in which an individual with damage to this region exhibited impaired priming and intact explicit memory function.

Other compelling evidence for multiple systems comes from neuroimageing. There is evidence that implicit memory is supported by neural processing that is qualitatively distinct from that supporting explicit memory. Functional magnetic resonance imageing (fMRI) studies indicate that explicit memory is associated with increased haemodynamic responses in prefrontal, parietal and medial temporal regions, while priming is associated with reduced responses in occipital, temporal, and prefrontal regions (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000; Henson, 2003; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Schacter, Alpert, Savage, Rauch, & Albert, 1996; Schott et al., 2005). Also, results from event related potential (ERP) studies point to distinct neurocognitive events responsible for explicit and implicit memory (e.g., Paller, Hutson, Miller, & Boehm, 2003; Rugg, Mark, Walla, Schloerscheidt, Birch, & Allan, 1998). In Paller et al.'s (2003) study, novel faces were encoded minimally (for 100 ms) to promote priming in the absence of explicit memory. It was reasoned that the brain potentials elicited by repeated faces would reflect the neural events responsible for priming, because the contributions from recognition would be negligible. Other faces were presented for a longer duration, for which recognition was above chance; thus the design provided a direct comparison of ERPs for recognition memory and priming not contaminated by explicit memory. Recognition was associated with positive potentials in posterior locations 400-800 ms after stimulus onset, while priming (based on the contrast between ERPs for primed-but-not-remembered items and new items) was associated with negative potentials at anterior locations 200-400 ms after onset.

1.1.2 The single-system perspective

The single-system view is that explicit and implicit forms of memory are driven by a unitary system and do not operate independently of one another. It has been argued that it is unnecessary to infer independent memory systems from evidence of single dissociations (e.g., Berry, Henson, & Shanks, 2006; Berry, Shanks, & Henson, 2008a; 2008b; Buchner & Wippich, 2000; Dunn, 2003; Nosofsky, Little, & James, 2012). There are several reasons why outcomes on direct and indirect memory tests may differ, even if the two measure exactly the same latent variable. First, indirect tasks are generally acknowledged to be statistically less reliable than direct memory tests (Buchner & Wippich, 2000; Meier & Perrig, 2000), meaning that it is more difficult to detect effects of independent variables in the former. Comparisons are frequently made between performance on recognition and word-stem completion tasks, but Buchner and Wippich (2000) demonstrated that the latter is a statistically less reliable test. They put this down to high levels of response variability due to inconsistencies between participants in their interpretation of the task instructions. That is, compared to a standard recognition task in which the goal to discriminate old from new items is relatively rigid, the instructions in a word-stem completion task – to complete stems with the first word that comes to mind – allow a considerable amount of flexibility in terms of the performance strategy that is adopted, especially when considering the many possible correct solutions. Overall, inherent differences in measure reliability make it difficult for one to conclude with full confidence that priming is completely unaffected by a manipulation that has an effect on explicit memory.

Evidence of priming in the absence of explicit memory is challenging to the single-system view, because if one assumes that a single source of memory drives performance on explicit and implicit tasks, and that the former is more sensitive, then priming should not occur when recognition is at chance. It is important to note, however, that to claim to have obtained chance recognition, one must be confident that the explicit test exhaustively indexed all the memory available to awareness (Shanks & St. John, 1994). Prior studies may not have met this criterion, and there have subsequently been several failed attempts to replicate the observation of intact priming coupled with chance recognition. For example, using the same method as Vuilleumier et al. (2005), and Butler and Klein (2009) (the RSVP task), Berry, Shanks, Li, Rains, and Henson (2010) found elimination of both priming and recognition for items that were unattended at study. Moreover, Moscovitch and Bentin (1993) found that priming was eliminated when recognition was reduced to chance by delaying testing.

Direct and indirect tasks typically differ in several other characteristics, such as retrieval cues, processing demands, and the type of response required, and in order to circumvent the issue that reported dissociations may reflect differences in task characteristics rather than differences in the memory systems they are assumed to tap, Reingold and Merikle (1988) proposed that direct and indirect tasks be made as comparable as possible by matching all characteristics except instructions. Using this approach, Merikle and Reingold (1991) reported an observation which they claimed reflects implicit in the absence of explicit memory. At study, participants named the cued member of a pair of words, and at test new and previously unattended (uncued) words were presented against a background mask. One group of participants were asked to judge whether each item was old or new (direct task), and a second group judged whether the contrast between the word and the background was high or low (indirect task). In fact the contrast between the word and background was held constant, and priming was inferred by the greater ease of processing old items, making them easier to perceive against the mask – that is, the contrast between the word and background was more likely to be judged as high when the word was old relative to when it was new. The key finding reported by Merikle and Reingold was robust priming for uncued items, while recognition of uncued items was at chance. This observation has been heavily cited in the literature as strong evidence for independent explicit and implicit memory systems, yet in a direct replication of this study, Berry et al. (2006) found, contrary to the original findings, that the sensitivity of the indirect task did not exceed that of the direct task, a finding that challenges the claim of implicit in the absence of explicit memory.

Another issue is that indices of explicit and implicit memory have traditionally been captured in separate experimental phases, which involves taking two samples of memory on different occasions. Even if comparable tasks are used, scores may dissociate because there is a longer study-test delay for one task than the other, or because participants adopt different response strategies or levels of motivation in the two tasks when they are presented separately, especially when one is conceivably more cognitively demanding than the other. For samples of explicit and implicit memory to be truly comparable, they need to be taken for the same items at around the same point in time (e.g., Stark & McClelland, 2000; Ward, Berry, & Shanks, in press). Dissociations produced under these circumstances constitute more persuasive evidence for multiple memory systems relative to when items are judged on two separate occasions.

Although there is often a heavy emphasis on differential effects of variables on explicit and implicit tests, there are many cases of associations (e.g., Berry et al., 2010; Moscovitch & Bentin, 1993; Ostergaard, 1998; Richardson-Klavehn & Bjork, 1988). This may point to a common mediator of explicit and implicit memory phenomena (although some have argued that it reflects contamination of the indirect task with explicit memory – this topic is discussed in more detail in section 1.3 of the Introduction). There are also published instances in which amnesic patients do not show spared implicit processing (Chun & Phelps, 1999; Squire, Shimamura, & Graf, 1987), and some functional imageing studies have indicated overlap in the regions involved in recognition and priming tasks (e.g., Jernigan & Ostergaard 1993; Schott et al., 2005). For example, Schott et al. (2005) found that old items that were primed but not explicitly recognised were associated with decreased activity in the hippocampus, a finding that is inconsistent with the multiple-systems view that priming is not dependent on this region.

Computational models can offer considerable theoretical insights regarding empirical dissociations, as the simulations provide a good account of the cognitive mechanisms underlying task performance. Formal single-system models have successfully reproduced several dissociations that have previously been taken as support for multiple memory systems (e.g., Berry et al., 2006; Berry et al., 2008a; 2008b; Berry et al., 2010; Berry, Shanks, Speekenbrink, & Henson, 2012; Kinder & Shanks 2001; 2003; Nosofsky et al. 2012; Shanks & Perruchet, 2002; Shanks, Wilkinson, & Channon, 2003). The model by Berry and colleagues assumes that a single memory signal drives performance on explicit and implicit tests, but that there are independent sources of random noise, the variance of which is greater in the latter (an assumption that is fortified by the generally lower reliability in implicit relative to explicit tests). The model has reproduced dissociations between recognition and priming such as those generated by manipulating attention at study (e.g., Butler & Klein, 2009), and those seen in individuals with amnesia due to damage to the hippocampus or medial temporal lobe (e.g., Conroy et al., 2005). These dissociations are thus not necessarily due to a selective influence of or deficit to an explicit memory system, but rather the inherent differences between the direct and indirect tasks used.

Until recently there have been few attempts to test formal multiple-systems models. Berry et al. (2012) developed two such models in which two independent signals either make unique contributions to performance on explicit and implicit tests or are assumed to have some degree of correlation. Not only did the single-system model reproduce the qualitative dissociation observed in amnesia in the Conroy et al. (2005) study, but model selection on the basis of the Akaike Information Criterion indicated that it fit the data better than the multiple-systems models. Thus, many empirical observations which on the surface appear to be indicative of multiple systems are not incompatible with the single-system view.

1.2 Memory and normal ageing

The present thesis considers the arguments for and against multiple memory systems that are based on memory changes across the lifespan. Ageing is linked to a variety of health issues, but perhaps the most well documented feature of growing older is that it is associated with cognitive and especially memory decline. Healthy older individuals often experience difficulties in remembering recently learned information, and perform worse than their younger counterparts on laboratory tests of explicit memory (reviewed in Kausler, 1994; Light, 1991). Because of this deficit in explicit memory function, there is a profound interest in establishing whether performance on implicit memory tests is affected by age. Despite decades of research, the answer to this question remains elusive. In the following subsections I outline the nature of the explicit memory deficit in normal ageing, and review the evidence for the preservation of implicit memory with age.

1.2.1 Explicit memory impairment

Explicit memory function is thought to increase throughout the teenage years before reaching a plateau at around age 25–30, after which it begins to steadily decline through adulthood (e.g., Nilsson, 2003). This progressive decline in the later adult years has been shown longitudinally (e.g., Christensen, Henderson, Griffiths, & Levings, 1997; Davis, Trussell, & Klebe, 2001; Fleischman, Wilson, Gabrieli, Bienias, & Bennet, 2004; Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992). Fleischman et al. (2004) reported steady declines in individuals with a mean age of 78.6 years over a four-year period on a battery of seven explicit tests involving immediate and delayed recall and recognition of stories, numbers and words, mostly taken from the Wechsler Memory Scale Revised (Wechsler, 1981). There is also an abundance of evidence from cross-sectional studies that individuals over the age of 60 perform less well than individuals in their twenties on tests of recall and recognition (e.g., Burke & Light 1981; Craik & Schloerscheidt, 2011; Howe; 1988; Hultsch & Dixon 1990; Jelicic, Craik, & Moscovitch, 1996), in addition to more ecologically valid explicit tasks such as remembering names and faces (Bahrick 1984; Cohen & Faulkner 1986; Maylor, 1990).

Age-related changes in explicit memory have been attributed to a host of structural and chemical changes in the brain, some of which begin in early adulthood and progress more rapidly in later adulthood (Dennis & Cabeza, 2008; Raz & Rodrigue, 2006). Most notably, there is widespread loss of white brain matter in structures within the medial temporal lobe, including the hippocampus and entorhinal cortex (Geinisman, Detoledo-Morrell, Morrell, & Heller, 1995; Kordower et al., 2001; Raz, Rodrigue, Head, Kennedy, & Acker, 2004; Small, Nava, Perera, Kelapex, & Stern, 2000; Stoub et al., 2005). This loss of tissue shows up as high signal intensity areas on MRI scans, also referred to as white matter hyperintensities. A major by-product of this is demyelination – a breakdown of the myelin sheaths around neurons that aid neuronal signal transmission. This affects signal conduction, and is thought to contribute to cognitive slowing and several other cognitive deficits, which may mediate the explicit memory impairment.

As a result of cognitive slowing, processing speed (the speed with which cognitive operations can be executed) declines steadily with age (e.g., Birren & Morrison, 1961; Craik & Rabinowitz, 1985; Eriksen, Hamlin, & Daye, 1973; Fisk & Rogers, 1991; Hasher & Zacks, 1979; Rabbitt, 1964; Salthouse, 1978; 1980), and it has been suggested that this may constrain the quantity of information that can be encoded into memory. Inefficient neuronal signal transmission may prevent new associations from being formed (MacKay &

Burke, 1990) and cause retrieval failures (Brown & Nix, 1996). Salthouse (1985) found that performance on the Digit Symbol Substitution Task (a standardised processing speed measure) correlated highly with performance on several explicit tests such as free recall, spatial recall, and paired associate learning.

Inhibitory control (the ability to control or suppress inappropriate or irrelevant responses or behaviours) is also diminished with age and is another potential mediator of explicit memory decline. Hasher and Zacks (1988) proposed that loss of inhibitory control (sometimes called attentional disregulation) makes the memory stores and processes of older individuals particularly susceptible to intrusion from irrelevant information. Indeed, studies using variations of the Stroop task (Stroop, 1935) suggest that older individuals are less able to ignore distracting information (Cohn, Dustman, & Bradford, 1984; Gopie, Craik, & Hasher, 2011; Langenecker, Nielson, & Rao, 2004). This may interfere with the processing of relevant information, and ultimately lead to memory failures (Zacks, Hasher, & Li, 2000).

There are several other proposals regarding the nature of the explicit memory deficit in normal ageing, such as failures of metamemory, the use of inappropriate encoding/retrieval strategies, and the weakening of the visual and auditory senses that are involved in the intake of information (for a thorough review see Light, 1991). It has also been suggested that memory traces are encoded less deeply in older individuals compared to young, and that older adults require greater environmental support (e.g., retrieval cues) in order to consciously access information stored in memory (Craik & Salthouse, 2008).

There is some disagreement with regards to the extent to which performance on different kinds of explicit tests is affected by age. In general there appear to be greater age-related deficits on tests of recall than recognition. Schugens, Daum, Spindler, and Birbaumer (1997) found consistent age-related deficits on immediate and delayed verbal and visual memory recall tasks, while age differences in recognition were not always present (see also Moscovitch & Winocur, 1992; Navehn-Benjamin & Craik, 1995). Greater environmental support is provided in recognition tasks, which may benefit the performance of older individuals, and the retrieval cues also limit the amount of self-initiated processing that is required (Craik & McDowd, 1987).

Another possibility is that the type of processing required to support recognition memory is dissimilar to that involved in recall, and the former is preserved in old age. A widely held view is that two separate processes support recognition memory: familiarity and recollection (e.g., Jacoby, 1991; Rotello, Macmillan, & Reeder, 2004; Wixted, 2007; Yonelinas, 2002; Yonelinas & Levy, 2002), and that successful recognition performance can rely on one or both processes. The familiarity process reflects the assessment of the memory strength of test items, and because recently studied items are more familiar than new items, this can serve as a basis to make positive recognition judgements. Recollection, on the other hand, occurs when specific associative information about the item is accessed, such as the context in which it was studied. Recollection processes are thought to decline with age, perhaps due to a reduction in the ability to effectively bind or associate units of information, while familiarity-based processing is spared (Light, Prull, La Voie, & Healy, 2000; Parks, DeCarli, Jacoby, & Yonelinas, 2010; Prull, Dawes, Martin, Rosenberg, & Light, 2006; Yonelinas, 2002; Jennings & Jacoby, 1993), and this may explain why performance on recognition tasks is sometimes similar in young and older individuals. On the other hand, the consistently reported age-related reduction in the ability to recall information from memory may reflect the more elaborate recollection-based processing required in this type of task.

1.2.2 Ageing and implicit memory

The explicit memory deficits that occur with age are similar to those seen in individuals with amnesia due to damage to the medial temporal lobe (Light & Singh, 1987). One might therefore expect implicit memory function to be preserved in old age as appears to be the case in amnesia. The evidence, however, is mixed (reviewed in Fleischman, 2007; Fleischman & Gabrieli, 1998; Mitchell, 1989). To date, all longitudinal studies have yielded a consistent observation: with advancing age, priming remains stable despite substantial declines in explicit memory (Christensen et al., 1997; Davis, Cohen, Gandy, Colombo et al., 1990; Davis et al., 2001; Fleishman et al., 2004; Hultsch et al., 1992). In cross-sectional studies comparing performance on implicit tasks in young and older individuals, age-invariant priming has been reported on tests of word-stem completion (e.g., Jelicic et al., 1996; Light & Singh, 1987; Park & Shaw, 1992; Mitchell & Bruss, 2003), word identification (e.g., Light, La Voie, Valencia-Laver, Albertson-Owens, & Mead, 1992; Light & Singh, 1987), picture naming (e.g., Mitchell, Brown, & Murphy, 1990; Sullivan, Faust, & Balota, 1995; Wiggs, Weisberg, & Martin, 2006), degraded picture naming (e.g., Russo & Parkin, 1993), and object decision (e.g., Schacter, Cooper & Valdiserri, 1992; Soldan, Hilton, Cooper, & Stern, 2009), yet there are also reports of age differences on some of the same implicit tests (e.g., Abbenhuis, Raaijmakers, Raaijmakers, & Van Woerden, 1990; Chiarello & Hoyer, 1988; Hultsch, Mason, & Small, 1991; Russo & Parkin, 1993).

The inconsistencies between studies may be due to methodological differences. Sample sizes have varied tremendously between studies, thus statistical power to detect group differences in priming is likely to have varied considerably. Priming was usually numerically lower in older relative to young adults, and a meta-analysis by La Voie and Light (1994) showed a small but significant effect of age on priming. The ability of different indirect tests to detect group differences in priming depends on their relative power and reliability, and Buchner and Wippich (2000) explicitly demonstrated that differences in measure reliability can explain the age differential pattern. However, the authors also demonstrated an instance in which a perceptual identification priming task had reliability levels equivalent to a direct recognition task, reasoning that the instructions in both tasks were equally restrictive and that speeded responding in the indirect task limited the variety of processes involved in its performance. Similarly, Salthouse, McGuthry, and Hambrick (1999) directly examined whether age differences on implicit learning tasks were attributable to differences in measure reliability. They showed that a sequential reaction time task had acceptable reliability levels, and was associated with a small but significant age effect. This measure was also positively related to objective measures of processing speed and explicit memory, which are known to be sensitive to age. They concluded that performance on this task does not reflect a qualitatively different type of processing to that involved in other indirect measures, and argued that the lack of age differences on a multitude of indirect tasks (and their weaker relationship with other cognitive variables) is simply due to lower measure reliability.

It is also likely that different indirect tasks are more or less sensitive to age effects depending on the specific cognitive processes they engage (Fleischman & Gabrieli, 1998). For example, it is thought that conceptual processing is affected by age to a greater extent than perceptual processing, so one might anticipate larger age-related deficits on conceptual indirect tasks than perceptual ones (see Geraci & Hamilton, 2009; Roediger & Blaxton, 1987). This seems to be the case in the literature. Furthermore, there is evidence that production processes tend to diminish with age, while identification processes are relatively spared (e.g., Rybash, 1996), and age-invariant priming has most often been reported on perceptual identification tasks, but not unfailingly on word-stem completion tasks, which require the production of a response. Lastly, priming appears to be least affected by age on tasks that use a latency measure and most affected on tasks that use an accuracy measure. This may, at least in part, be due to the fact that older individuals are slower to respond in general, and a longer baseline response speed (i.e., for items that are new at test) can artificially magnify the calculated priming effect by allowing more room for improvement (Fleischman, 2007).

Participant characteristics such as age and cognitive status have also varied across studies. Participants aged 60-70 years (often referred to as young-old) often demonstrate less of a priming deficit in relation to participants aged over 70 (often referred to as old-old) (e.g., Davis et al., 1991; Maki, Zonderman, & Weingartner, 1999). A similar pattern is true of explicit memory deterioration, and while this may merely indicate the progressive nature of memory decline with age, it may also indicate the pathology of non-normal changes in memory. It is important to note the importance of focussing on normal ageing in addressing the question of whether implicit memory phenomena are age-invariant. Alzheimer’s disease (AD) is associated with substantially more neural degeneration than normal ageing, in addition to the characteristic amyloid plaques and neurofibrillary tangles, which affect neocortical regions as well as structures within the medial temporal lobe (e.g., Brun & England, 1981). This contributes towards the profound deficit in explicit memory (Carlesimo & Oscar-Berman, 1992; Spaan, Raaijmakers, & Jonker, 2003), and also typically affects performance on implicit tasks (reviewed in Fleishman, 2007). Although the studies reviewed above were based on older participants who did not meet the criteria for dementia, in some cases the participants were not normal either. Some had what is now termed Mild Cognitive Impairment (MCI), meaning that they are at a heightened risk of developing AD (e.g., Bennett et al., 2002). Although there is some disagreement with regards to the extent of the cognitive deficits that occur in MCI, these may interfere with performance on a range of indirect tests, so including such individuals in studies hinders our understanding of whether implicit memory processing is attenuated in normal ageing (see Fleishman, 2007).

In sum, the small reduction in priming reported in the La Voie and Light (1994) meta-analysis may reflect a genuine decline with age in performance on implicit tasks, but could also merely reflect differences in task and participant characteristics. It remains to be seen whether implicit memory function is preserved or diminished in normal ageing.

1.3 Theoretical considerations

How can we shed light on the question of whether explicit and implicit forms of memory are driven by a single or multiple systems? Normal ageing provides a fruitful platform from which to examine the problem because, as we have seen above, cognitively healthy older individuals are known to have deficits in explicit memory function. This provides an opportunity to test the principal prediction of the multiple-system view: that older adults are capable of performing equivalently to young individuals on tests of implicit memory, despite weaker performance on explicit tests. Robust empirical evidence from which inferences can be drawn is currently limited due to the discrepancies in the literature and the criticisms of prior methodologies. To make progress, one must attempt to provide solid evidence that implicit memory function is completely preserved in old age (i.e., equivalent priming in young and older adults) in the face of compromise to explicit memory functioning, rather than simply demonstrating that the performance of young and older adults on implicit tests is not statistically different. This thesis seeks to establish whether such a pattern can be produced. Next follows a brief review of the factors I deemed important to consider or control in this research.

1.3.1 Considerations for comparisons of different age groups

I aimed to ensure that any differences between young and older individuals on the memory measures were not exacerbated by extraneous factors. Memory can vary between cohorts as a function of differences in factors other than age, such as intelligence and the level of formal education achieved (e.g., Christenson & Birrell, 1991), so it is essential to attempt to recruit comparable samples of young and older participants. In the experiments reported in this thesis, I used fixed age limits of 18-30 years (young groups) and 60-80 years (older groups), and all samples were matched as far as possible on the number of years spent in formal education. All participants were educated to degree level, and engaged in some form of active learning at the time of testing. All young adults were undergraduate or postgraduate students from University College London (UCL) and all older adults were members of a local adult education centre or the University of the Third Age (U3A; www.u3a.org.uk) organisation. All participants were deemed physically and mentally healthy (via the use of a self-report questionnaire), and were free from medications that are thought to affect cognitive function (e.g., antihypertensive drugs).

Pre-morbid intelligence, processing speed, and vision were objectively measured in all participants using standard tests, to allow insight as to whether any group differences in priming are related to these factors. Further details about the tasks used and administration are provided in Chapter 2 when the testing procedures are explained. No older participants met the criteria for MCI or dementia – all were screened for cognitive impairment using the Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975), with the a priori decision to exclude the data of individuals with scores less than 23/30 (based on the guidelines for interpretation of the exam scores, which state that a score of 23 or lower likely indicates cognitive impairment). In practise, no participant in any experiment reported in this thesis scored below this threshold.

The present priming task involved a response time (RT) measure (see section 1.3.2 below). A prominent issue that has not in the past received the attention it deserves is the way in which priming is calculated for the purposes of making comparisons of different age groups when using latencies as the dependent variable. As we saw above, older individuals are generally slower to respond than young adults (e.g., Salthouse, 1985), and a slower baseline (new item) RT can artificially elevate the priming calculation when an absolute difference score is used (i.e., RT new items minus RT old items). Between-group differences in baseline RT were accounted for in the present experiments by calculating priming scores in proportion to the individuals' baseline RT (i.e., [RT new – RT old] / RT new); a proportion transformation, as it is commonly known. This is generally deemed to be the best method of calculating priming for the comparison of independent groups with dissimilar baseline response speeds, and it has been successfully applied by several others in the past (e.g., Hartley, 1993; Chapman, Chapman, Curran, & Miller, 1994; see Faust, Balota, Spieler, & Ferraro, 1999, for further discussion of the implications of age-related generalised slowing).

1.3.2 Comparable samples of explicit and implicit memory

The ambiguities that may arise as a result of using direct and indirect tasks with dissimilar processing demands, retrieval cues and/or response metrics have received a lot of attention, but prior conclusions are also limited due to the fact that samples of explicit and implicit memory are typically taken in separate experimental phases. Capturing a measure of explicit and implicit memory for a given test item in the same individual at around the same point of time allows much greater theoretical transparency. Not only does this ensure that the samples of memory are as comparable as possible and unaffected by shifts in strategy, motivation, and so on, but it allows one to examine certain predictions that are inherent in the multiple-systems account. A pure independence account states that performance on a priming task (e.g., speeded perceptual identification) is unrelated to performance on a recognition task, so one can test the prediction that identification latencies will be equivalent for old items that are recognised (hits) and those that are forgotten (misses). Differences occurring at the item level when the priming task immediately precedes recognition constitute compelling evidence for independent systems – if the two are driven by the same system and measured at approximately the same point in time, differences should not occur.

Stark and McClelland (2000) investigated the relationship between recognition and priming using the continuous identification with recognition (CID-R) task, in which the two are measured concurrently on each test trial. In the test phase, old and new items (words) gradually clarified from a background mask and participants were asked to identify the item as quickly as possible (yielding a priming measure) before indicating whether they believed the item had been previously studied (yielding a recognition measure). They found robust priming for recognition misses, which was taken as support for multiple-systems. This task was also employed by Conroy et al. (2005) in their examination of recognition and priming in amnesia, but to my knowledge this approach has never before been used to examine the relationship between recognition and priming in normal ageing. The studies presented in this thesis are the first to compare the performance of young and older individuals on the CID-R task. Briefly, following a study phase in which a series of pictures of objects is presented, each trial of the CID-R task involved a speeded masked picture identification (priming measure) followed immediately by an old/new recognition judgement for the item. The experimental procedure for the CID-R task is described in more detail in Chapter 2.

1.3.3 Explicit contamination

Sometimes experimental manipulations have an effect on indices of implicit memory. For example, performance on implicit word-stem completion tasks is often sensitive to ageing (e.g., Chiarello & Hoyer, 1988; Davis et al., 1990, Exp 2; Hultsch, Masson, & Small, 1991) and depth of processing (e.g., Richardson-Klavehn & Gardiner, 1998). It is often argued that this reflects the use of explicit or intentional retrieval strategies. That is, if participants notice during an implicit test that some items were previously shown in the study phase (termed 'test awareness'), they may adopt a voluntary explicit processing strategy to perform the supposedly implicit task. In the case of word-stem completion, instead of completing stems with words that first come to mind, they may try to explicitly recall items from the prior study episode. It is therefore possible that instances whereby performance on an implicit test has been affected by an experimental factor in a similar way to explicit memory are merely reflective of an index of explicit memory. This issue is especially important to consider with regards to the topic of cognitive ageing: using an implicit task that is susceptible to explicit contamination may be more likely to result in impaired performance on implicit tests in older individuals compared to young, because young individuals are in a better position to take advantage of explicit processing (e.g., Mitchell & Bruss, 2003; Russo & Parkin, 1993). For example, Russo and Parkin (1993) found an age difference in priming on a fragmented picture completion task, an effect which disappeared when explicit memory performance was equated between groups by asking young individuals to perform a dual task at study.

Under what conditions are participants likely to engage in an explicit strategy while performing an indirect memory test? Arguably, for this to occur participants must have to become test-aware. Many techniques have been put in place to prevent conscious intrusion in implicit memory tests, such as adequately disguising tests, presenting stimuli very briefly, and using speeded tasks (reviewed in MacLeod, 2008). The effectiveness of such measures is difficult to appraise because test awareness is often evaluated post hoc using self report questionnaires (e.g., Bowers & Schacter, 1990), and the validity of such measures is questionable (e.g., Reingold & Toth, 1996; but see Barnhardt & Geraci, 2008). There is evidence that test awareness mediates the effects of some manipulations on priming (e.g., Bowers & Schacter, 1990; Geraci & Barnhardt, 2010), and this is an important consideration in the present thesis because the CID-R task employed here is not performed under standard implicit instructions – participants are informed that some items are old and are required to make a recognition judgement after every picture identification. As such, I directly examined the contributions of test awareness and explicit processing to priming in the CID-R task. I revisit the problem of explicit contamination in the latter part of Chapter 2, and again in Chapters 3 and 4.

1.4 Overview of thesis

Drawing on what we have learned over the past few decades of research on explicit and implicit memory, and the considerations that must be put in place in order to make theoretical advancement, this thesis aims to shed light on whether these two forms of memory are driven by the same or functionally independent cognitive systems. As outlined above, I attempted to make progress by comparing the performance of healthy young and older individuals on the CID-R task, which captures a measure of priming and recognition for each item concurrently at test. The question of interest is whether priming (a measure of implicit memory) is unaffected by normal ageing despite age-related reductions in recognition memory (an index of explicit memory). This question is the direct focus of the experiments presented in Chapter 2. To preview, both priming and recognition memory are affected by age. Chapters 3 and 4 present a thorough examination of the effects of test awareness and explicit processing on the priming (CID) task (explicit contamination). I present a range of evidence that priming in this task is unaffected by explicit strategies, and conclude that the age-related reduction in priming is genuine and not due to the use of explicit processing which enabled the performance of young adults to be boosted. Overall, the results are consistent with a unitary account of memory.

Chapter 2: Explicit and Implicit Memory in Normal Ageing

Three experiments examined whether priming is affected by normal ageing in a similar way to recognition memory. The performance of young and older adults on the picture CID-R task was compared, and the delay between the study and test phases (60 min versus no delay) was also manipulated. Recognition memory is typically affected by age and is prone to rapid forgetting over time (e.g., Mitchell et al., 1990), thus the rationale for combining these factors was to degrade a sample of explicit memory as much as possible, to allow us to test the competing predictions of the multiple and single-system perspectives regarding the effect on priming. The multiple-systems account predicts no effect of age or delay on priming, while the single-system view predicts an effect on priming that is likely to be smaller than that on recognition memory due to lower task reliability.

2.1 Experiment 1

In Experiment 1 participants studied pictures of everyday objects and were tested on half the items immediately following study (immediate CID-R test), and the other half following a 60 minute delay (delayed CID-R test).

2.1.1 Method

2.1.1.1 Participants

Twenty young and 20 older adults participated in the study for a payment of £5. There were eight men and 12 women in each group. The young adults were students from UCL, recruited through an advertisement on a participant database, and the older adults were recruited from a local adult education centre. All participants were native English speakers who reported good health. Participant demographic information and the scores on standard neuropsychological tests are summarised in Table 2.1.

2.1.1.2 Stimuli

In this and subsequent experiments, the stimuli were pictures of everyday objects from ten categories: animals, clothing, fruit and vegetables, electrical appliances, musical instruments, transportation vehicles, kitchen utensils, insects, tools, and furniture. Items were selected on the basis of the category norms collected by Van Overschelde, Rawson, and Dunlosky (2004). In Experiment 1 there were 120 critical items, each depicting a colour photograph of a single object on a 400 x 400 pixel white background (Figure 2.1A). Sixty pictures, six from each object-category, appeared in the study phase and were split evenly between the two CID-R test phases to serve as old items. The other 60 pictures served as new items, 30 presented in each test. Counterbalancing was achieved by rotating four sets of 30 pictures between participants to serve as old/new items and to appear in the immediate/delayed test phase. The mask used in the identification task was a 400 x 400 pixel grid randomly filled with fragments of non-critical pictures.

Table 2.1. Participant characteristics in Experiment 1.

	Young (*n* = 20)	Older (*n* = 20)
	M (SD)	*M (SD)*
Age (years)	23.4 (3.2)	65.8 (5.5)
Education (years)	15.3 (2.6)	17.4 (4.5)
Visual acuity	31.8 (8.1)	34.4 (7.4)
WAIS-III Vocabulary *	48.0 (3.4)	61.7 (8.7)
WAIS-III Digit Symbol (processing speed) *	74.3 (14.4)	55.0 (11.6)
Wechsler Test of Adult Reading (WTAR)	44.7 (3.2)	46.8 (1.7)
Mini Mental State Exam (MMSE)	-	28.4 (1.2)

Note. Visual acuity was measured using the Near Vision Test Card (Schneider, 2002), viewed at a distance of 16 inches (40 cm) whilst wearing corrective glasses. Participants indicated the smallest set of letters that they could comfortably read (scores can range from 16 (highest acuity) to 160 (lowest acuity). The WAIS-III (Wechsler Adult Intelligence Scale III) Vocabulary test (maximum score = 66) involves defining 35 English words and is a standard measure of verbal comprehension which correlates highly with IQ. The WAIS-III Digit Symbol Substitution Test (maximum score = 133) involves copying a coding pattern into a grid, and is a standardised measure of processing speed. The WTAR (maximum score = 50) involves reading a list of 50 English words with irregular pronunciations and is a standardised measure of pre-morbid intellectual functioning. Finally, the MMSE (maximum score = 30) is an objective clinical screening test for cognitive impairment. Scores on this test ranged from 27 to 30, and no participant neared the imposed cut off limit of 23.

* Significant difference between groups, $p < .05$

2.1.1.3 Design and procedure

The experiment used a mixed factorial design with the between-subjects factor age group (young vs. older adult) and the within-subjects factor delay (60 min vs. no delay). The experimental procedure, identical for both groups, consisted of four parts: a study phase, an immediate CID-R test, a 60 minute interval, and a delayed CID-R test. Participants were tested individually, and the duration of the experiment was approximately 90 minutes per participant. The two groups of participants were run simultaneously (that is, one group was not completed before the other). In this and subsequent experiments, the task was programmed in Matlab 6 using the Cogent Toolbox and administered on a PC with a screen resolution of 1024 x 768 pixels. Viewing distance was approximately 50 cm.

Study phase. Participants performed an incidental encoding task which involved matching briefly presented pictures to object-categories. Each trial was presented as follows: (1) a fixation point ('+') was presented at the centre of the screen for 500 ms, (2) a picture (e.g., a dog) was presented for 250 ms, (3) the instruction "Which category was the object from?" appeared at the top centre of the screen, and two category options were displayed (e.g., F = animal / J = musical instrument). Participants were instructed to use the 'F' and 'J' keyboard keys to select the correct option. No time limit was imposed on participants to respond, and the choice categories remained on the screen until a keypress was made; (4) finally, there was a 1000 ms blank screen prior to the start of the next trial. There were 60 randomised trials in total, plus 5 practice trials.

Immediate CID-R test. Immediately following the study phase, participants were given instructions for the CID-R task. Participants were not informed of either CID-R phase in advance. Each trial consisted of a speeded masked-picture identification in which response times (RT) were measured, and a recognition judgement. Each trial was self-initiated by the participant, and began with the identification task as follows: A mask (see Figure 2.1) was initially presented at the centre of the screen for 500 ms. A picture (old or new) was then presented for 17 ms, followed immediately by the mask for 233 ms (making a 250 ms block). These block presentations were repeated, with the duration of picture presentations increasing by 17 ms on every alternate block while the total block duration remained constant, thus making the picture gradually more visible (Figure 2.1B). Participants were required to identify the picture as quickly and accurately as possible, pressing the 'Enter' key when they knew the identity of the object. RTs in milliseconds were captured on the keypress, at which point the picture disappeared and participants were prompted to type the object name into a box. The block presentations ceased at 7 sec (30 blocks) after initiation if identification had not taken place, and any such trials were discarded.

The recognition segment of the trial immediately followed each identification. The picture was presented once more and participants were required to make a judgement as to whether they thought it was shown in the study phase using a 6-point scale where 1 = *very sure no*; 2 = *fairly sure no*; 3 = *guess no*; 4 = *guess yes*; 5 = *fairly sure yes*; 6 = *very sure yes*. In practise, all experiments yielded a clear and substantial age difference in recognition when scores were collapsed by '*yes'* (4-6) and *'no'* (1-3) ratings, however the purpose of using the scale was to allow a more in-depth analysis of the data should there be need (i.e., by breaking accuracy down by confidence). No time limit was imposed in making recognition judgements, and no feedback was provided. There were 60 randomised trials in total – 30 old (half the items presented at study) and 30 new, plus 5 practice identification (CID) trials.

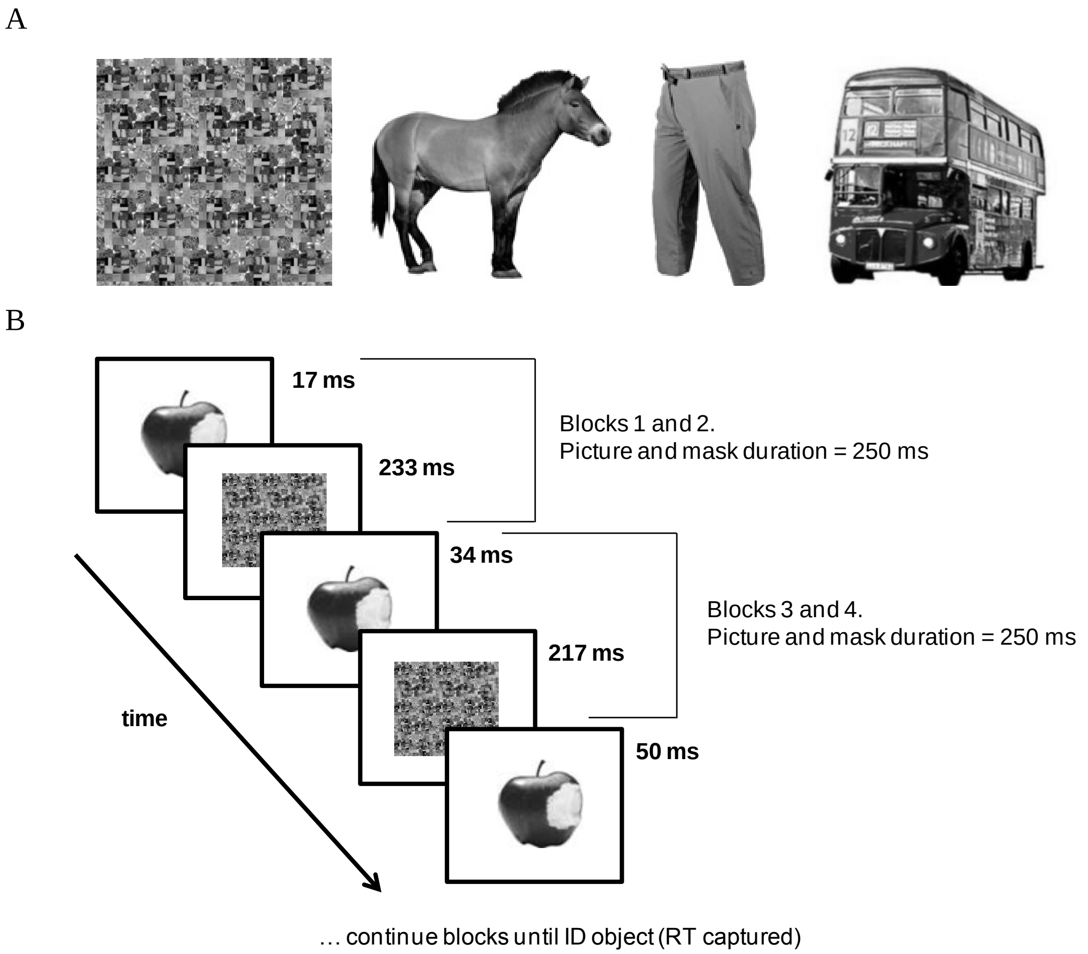

Figure 2.1. A: Priming mask used in the identification (CID) task and examples of picture stimuli. B: Example of the CID portion of the CID-R trial.

Interval. The interval between the immediate and second CID-R tests was 60 minutes. The following battery of tests was administered: (1) Demographic and health questionnaire, (2) Near Vision Test, (3) Wechsler Test of Adult Reading (WTAR), (4) WAIS-III

Vocabulary and Digit Symbol Substitution tests, (5) Mini Mental State Exam (older adults only). Breaks were provided where needed.

Second CID-R test. Following the interval, participants performed the second CID-R task, which was identical in procedure to the immediate test. In this phase, the other 30 previously studied pictures were presented along with 30 new items.

2.1.2 Results and Discussion

In this and subsequent experiments, an alpha level of .05 was used for all statistical tests, and all *t*-tests were two-tailed unless otherwise stated. Cohen's *d* and partial eta squared are provided as an indication of the effect size of significant comparisons and main effects.

2.1.2.1 Study

Accuracy in picture-word matching was high for both young (*M* = 95.4%; *SD* = 3.9) and older (*M* = 94.3%; *SD* = 5.8) adults, and performance was not statistically different between groups, $t(38) = 0.70$, $p = .49$. In this and all subsequent experiments, items associated with incorrect study phase responses were removed from all further analyses. Study phase response times did not significantly differ between groups (young *M* = 636 ms, *SD* = 368; older *M* = 815 ms, *SD* = 337, $t(38) = 1.60$, $p = .12$).

2.1.2.2 Recognition

Ratings 4-6 ('*yes'* – old) and 1-3 (*'no'* – new) on the 6-point scale were collapsed (see page 30). For each participant, the proportion of hits (old pictures judged old) and false alarms (new pictures judged old) in each test phase were used to calculate d' (z-transformed hits minus false alarms; Figure 2.2). The proportions of hits and false alarms can be found in Table A1 in the Appendix.

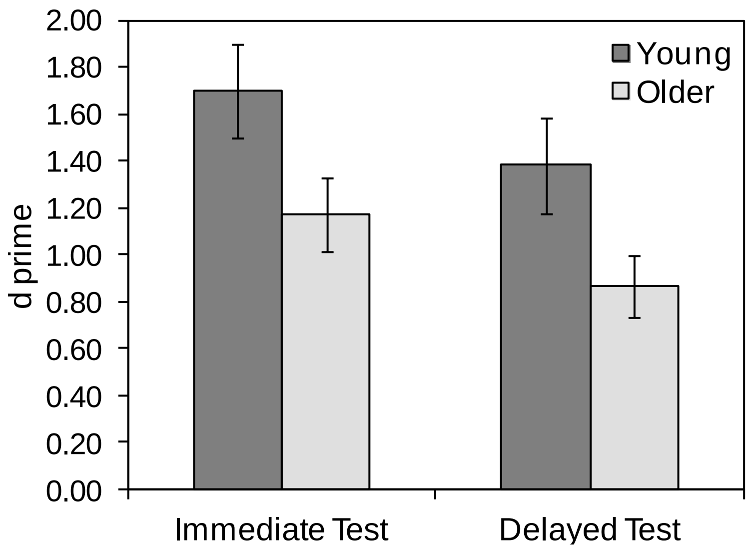

Figure 2.2. Mean *d'* scores for young and older adults in Experiment 1 as a function of delay. Error bars indicate standard error of the mean (SEM).

Discrimination was significantly greater than chance (i.e., *d'* > 0) on the immediate test ($t(19) = 8.54$, $p < .001$, and $t(19) = 7.35$, $p < .001$, for young and older adults, respectively), and the delayed test ($t(19) = 6.69$, $p < .001$, and $t(19) = 6.61$, $p < .001$, for young and older adults, respectively). A repeated measures ANOVA with age group as a between-subjects factor revealed a significant main effect of age group, $F(1, 38) = 5.61$, $p = .02$ ($\eta_p^2 = .13$), and delay, $F(1, 38) = 6.81$, $p = .01$ ($\eta_p^2 = .15$), and a non-significant interaction, $F(1, 38) < 0.01$, $p = .96$. Young adults achieved significantly better recognition scores than older adults on the immediate test, $t(38) = 2.06$, $p = .046$, $d = 0.65$, and the delayed test, $t(38) = 2.10$, $p = .04$, $d = 0.66$. Correct recognition was significantly higher on the immediate relative to the delayed test for older adults, $t(19) = 2.36$, $p = .03$, $d = 0.47$, but this difference did not reach significance in the young adult group, $t(19) = 1.58$, $p = .13$. There was no significant difference in response bias (criterion; *C*) between the two groups on either test phase (young immediate test: $C = .17$, $SD = .23$; young delayed test: $C = .21$, $SD = .33$; older immediate test: $C = .33$, $SD = .32$; older delayed test: $C = .39$, $SD = .42$, $F(1, 38) < 1$, $p > .05$).

2.1.2.3 Priming

The following steps were performed on each participant's raw RT data (Table 2.2) to obtain a priming score: (1) Trials associated with incorrect identifications were removed; (2) Identification RTs (ms) for old and new items were averaged separately and trials with latencies faster than 200 ms or greater than 2.5 SD from the mean were removed, so as to avoid extreme values; (3) Priming was then calculated as the difference in the median RT between new and old items, expressed in proportion to the individual's baseline (new item)

RT. Priming scores were averaged within each group (Figure 2.3). That is, priming = (RTnew – RTold) / RTnew. A proportional priming score was used as baseline (new item) identification times were generally slower in older relative to young adults. Median identification times were used as mean RTs were positively skewed. The exclusion of trials based on the criteria above (i.e., incorrect identifications etc) totalled 368 out of a total 4800 trials (7.67%) across participants, 230 for young adults, and 138 for older adults.

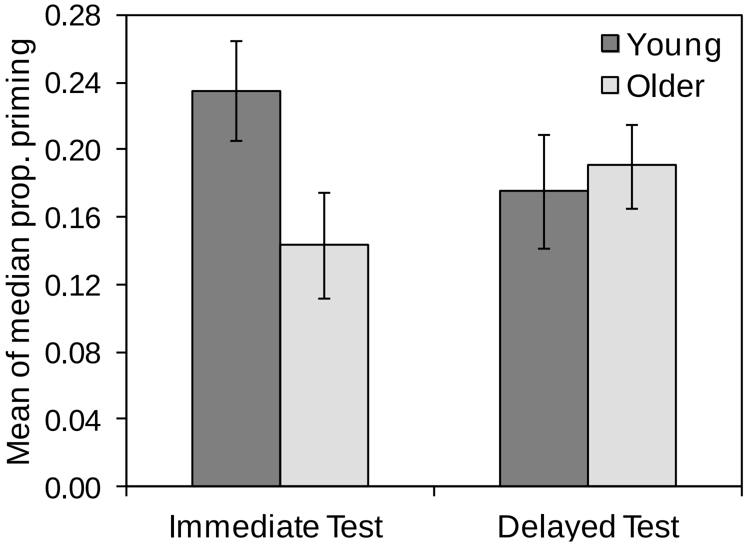

Figure 2.3. Mean of median proportion priming in young and older adults in Experiment 1 as a function of delay. Error bars indicate SEM.

Priming was strong and significantly greater than zero on the immediate test ($t(19) = 8.01$, $p < .001$, and $t(19) = 4.54$, $p < .001$, for young and older adults, respectively), and the delayed test ($t(19) = 5.22$, $p < .001$, and $t(19) = 7.57$, $p < .001$, for young and older adults, respectively). An ANOVA revealed no main effect of age-group, $F(1, 38) = 1.35$, $p = .25$, or delay, $F(1, 38) = 0.06$, $p = .81$, but a marginally significant interaction between the factors, $F(1, 38) = 4.00$, $p = .053$, $\eta_p^2 = .09$. Follow-up tests indicated that priming was significantly lower for older relative to young adults on the immediate test, $t(38) = 2.14$, $p = .04$, $d = 0.68$, while there was no group difference in priming on the delayed test, $t(38) = 0.36$, $p = .72$. Priming in young adults did not significantly differ between the immediate and delayed tests, $t(19) = 1.24$, $p = .23$, however there was a small increase in priming between the two tests in the older adult group which approached significance, $t(19) = 2.02$, $p = .06$, $d = 0.37$.

On average it took young participants 16.6 minutes to complete the initial test phase, and 15.2 minutes to complete the delayed test phase, whereas older participants completed the initial test phase in an average of 19.4 minutes, and the delayed test phase an average of 20.1 minutes to complete. The identification times of older adults were generally slower than those of young adults, as can be seen in Table 2.2, but it is also likely that older adults spent longer inputting the object names via the keyboard (although there is no data to confirm this).

Table 2.2. Mean of median identification RTs for old and new items in the young and older adult groups in Experiment 1.

	Young		Older	
	Old	New	Old	New
Immediate Test	1584 (439)	2138 (683)	2148 (676)	2523 (731)
Delayed Test	1891 (656)	2271 (612)	2345 (697)	2906 (793)

Note. Standard deviations in parenthesis. Identification times were generally slower in older relative to young adults, *t*'s > 2, *p*'s < .05.

2.1.2.4 Other analyses

Correlation. Collapsed across age group and delay, there was a significant positive correlation between priming and *d′* scores, $r = .46$, $p < .001$.

Old item priming. If priming and recognition are independent, then identification latencies should be equivalent for old items that were successfully recognised (hits) and those that were not (misses). In this experiment, RTs were significantly reduced for hits relative to misses on the immediate test (young adults: hits: *M* = 1562 ms, *SD* = 445, misses: *M* = 1943 ms, *SD* = 741, $t(19) = 2.99$, $p = .01$, $d = .62$; older adults: hits: *M* = 2068 ms, *SD* = 597, misses: *M* = 2360 ms, *SD* = 744, $t(19) = 2.71$, $p = .01$, $d = .43$), and for young adults on the delayed test (young adults: hits: *M* = 1789 ms, *SD* = 604, misses: *M* = 2074 ms, *SD* = 741, $t(19) = 2.79$, $p = .01$, $d = .42$; older adults: hits: *M* = 2275 ms, *SD* = 634, misses: *M* = 2420 ms, *SD* = 819, $t(19) = 1.64$, $p = .12$).

Priming was also examined in individuals who achieved very low levels of recognition (*d´* of 0.5 of less), to establish whether priming can persist in such cases. Evidence of robust priming in instances where recognition is weak or at chance could be taken as evidence for multiple systems. All participants obtained scores in excess of this limit on the immediate test, so this analysis included 3 young and 5 older participants who met this criterion on the delayed test. Priming in these individuals was not significantly different from zero: young: *M* = -.02, *SD* = .10, $t(2) = 0.41$, $p = .72$; older: *M* = .12, *SD* = .15, $t(4) = 1.84$, $p = .14$.

In sum, the outcomes of the recognition test were as expected: performance was compromised by age and delay. In contrast, the priming results were mixed. Priming was lower in older relative to young adults on the immediate test, but equivalent between groups on the delayed test. Priming increased somewhat in older adults over the delay, and it is possible that this is an artefact of using two separate CID-R tests: Baseline identification times slowed disproportionately for older adults in comparison to young on the delayed test, which potentially affected the priming calculation despite the fact that a proportional measure was used. It is also possible that including two separate tests inadvertently encouraged differences in the way in which they were performed. These issues were addressed in Experiment 2.

2.2 Experiment 2

Experiment 2 was a replication of Experiment 1 with a minor but important methodological adjustment: young and older participants performed a single CID-R task comprised of items that were either studied immediately prior to or 60 minutes prior to the test. This constituted a similar manipulation of delay, and ruled out the potential problems associated with having two separate CID-R test phases.

2.2.1 Method

2.2.1.1 Participants

Twenty young (seven male) and 20 older (two male) adults participated for a small payment. The young adults were UCL students, again recruited through the online participant database, and the older adults were members of the U3A. All were native English speakers who reported good health. Participant demographic information is summarised in Table 2.3.

2.2.1.2 Stimuli and procedure

The pictures, categories and priming mask were the same as those used previously. Sixty pictures were presented in the study phases (30 in each phase), and served as old items at test. An additional 60 pictures were presented at test to serve as new items.

The experimental procedure was very similar to that in Experiment 1. Participants first performed the initial study phase in which they matched 30 briefly presented pictures of objects to categories. Then followed a 60 minute interval in which the same battery of neuropsychological tests was administered. Participants then performed the second study phase, in which they saw a different set of 30 items, and finally the CID-R task, which included 120 items in total – 60 old (30 from each study phase), and 60 new. The experimental procedure was again around 90 minutes, and breaks were provided in the interval if needed.

Table 2.3. Participant characteristics in Experiment 2.

	Young (n = 20)	Older (n = 20)
	M (SD)	*M (SD)*
Age (years)	24.3 (3.8)	69.1 (5.5)
Education (years)	16.5 (1.2)	15.9 (2.5)
Visual acuity *	27.0 (5.5)	32.6 (6.1)
WAIS-III Vocabulary *	54.9 (10.2)	64.7 (2.2)
WAIS-III Digit Symbol *	89.9 (14.0)	66.4 (15.8)
WTAR	46.9 (3.8)	48.8 (2.5)
MMSE	-	29.8 (0.6)

Note: Scores on the MMSE ranged from 28 to 30, and no participant neared the imposed cut off limit of 23

* Significant difference between groups, $p < .05$

2.2.2 Results

2.2.2.1 Study

Mean categorization accuracy was at 98.3% (*SD* = 2.29) for young and 96.5% (*SD* = 4.77) for older adults on the initial study phase, and 97.7% (*SD* = 3.26) for young adults and 98.5% (*SD* = 2.53) for older adults on the second study phase. Performance was not statistically different between groups in either phase: $t(38) = 1.55$, $p = .13$, and $t = 0.90$, $p = .37$, for the initial and second study phases, respectively. In this experiment, study phase response times were significantly faster for young (*M* = 1345 ms, *SD* = 305) relative to older (*M* = 1886 ms, *SD* = 447) adults in the initial study phase, $t(38) = 4.47$, $p < .001$, $d = 1.41$, and in the second study phase (young *M* = 1190 ms, *SD* = 311; older *M* = 1604 ms, *SD* = 450, $t(38) = 3.38$, $p = .002$, $d = 1.07$).

2.2.2.2 Recognition

Recognition (d'; Figure 2.4) was significantly greater than chance for young and older adults, for items studied immediately prior to testing and those studied 60 min prior to testing (all *t*'s > 7, all *p*'s < .001). There was a significant main effect of age group, $F(1, 38) = 4.26$, $p = .04$, $\eta_p^2 = .10$, and delay, $F(1, 38)$, = 5.76, $p = .02$, $\eta_p^2 = .13$, and no significant interaction between the factors, $F(1, 38) = 0.16$, $p = .69$. Item discrimination was superior in young relative to older adults for items studied immediately prior to testing, $t(38) = 2.03$, $p = .05$, $d = 0.64$, and items studied 60 min prior to testing, $t(38) = 1.78$, $p = .04$, $d = 0.56$ (one-tailed). Recognition was significantly reduced for items studied 60 min prior to testing relative to those studied immediately before for young adults, $t(19) = 1.67$, $p = .05$, $d = 0.32$, and older adults, $t(19) = 1.83$, $p = .04$, $d = 0.32$ (both one-tailed). There was no significant difference in response bias between young and older adults (young immediate items: $C = 32$, $SD = .41$; young delayed items: $C = .14$, $SD = .47$; older immediate items: $C = .22$, $SD = .37$; older delayed items: $C = .29$, $SD = .41$, $F(38) = 1.85$, $p = .18$).

2.2.2.3 Priming

A total of 298 out of 4800 trials (6.21%) across participants were removed due to incorrect identifications etc (171 for young adults and 127 for older adults). Priming (Figure 2.4; see Table 2.4 for identification RTs) was significantly above zero for items studied immediately prior to testing ($t(19) = 3.68$, $p = .002$, and $t(19) = 2.80$, $p = .01$, for young and older adults, respectively), and items studied 60 min prior to testing ($t(19) = 4.60$, $p < .001$, and $t(19) = 2.78$, $p = .01$, for young and older adults, respectively). However, a repeated measures ANOVA with the between-subjects factor age-group revealed no significant main effect of age group, $F(1, 38) = 1.78$, $p = .19$, or delay, $F(1, 38) = 0.02$, $p = .89$, and no significant interaction, $F(1, 38) = 0.04$, $p = .85$.

On average it took young participants 28.7 minutes to complete the test phase, while it took older participants an average of 36.5 minutes to complete.

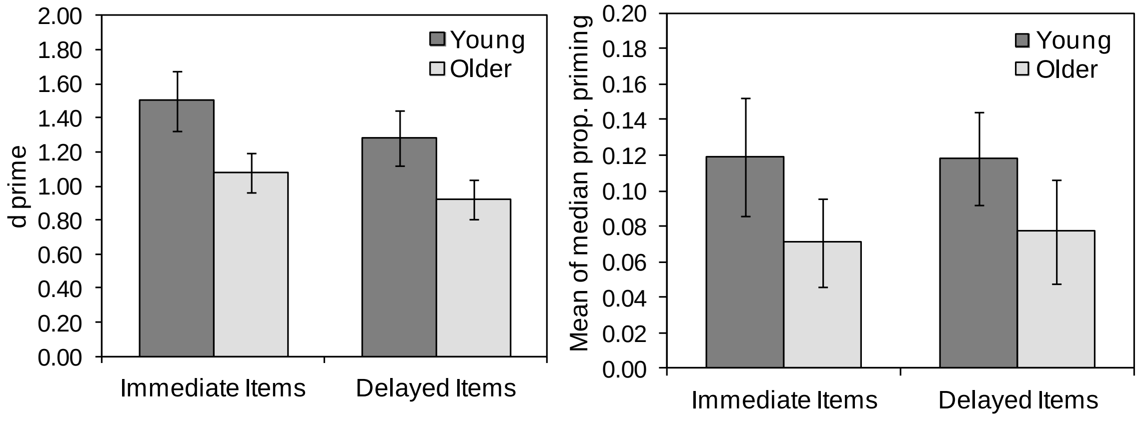

Figure 2.4. Left panel: Mean *d'* scores for young and older adults in Experiment 2 as a function of delay. Right panel: Priming scores. Error bars represent SEM.

2.2.2.4 Other analyses

Correlation. Collapsed across age-group and delay, there was a significant positive correlation between priming and *d′* scores, $r = .29$, $p < .005$.

Old item priming. Identification latencies were significantly more rapid for hits relative to misses for items studied immediately before testing in the young adult group (hits: $M = 1079$ ms, $SD = 368$, misses: $M = 1281$ ms, $SD = 403$, $t(19) = 2.46$, $p = .02$, $d = .53$), but this difference did not reach significance in the older adult group (hits: $M = 1817$ ms, $SD = 607$, misses: $M = 1968$ ms, $SD = 713$, $t(19) = 1.30$, $p = .21$). RTs for hits were faster than RTs for misses for items studied 60 min prior to testing in both groups, but these differences fell short of significance (young adults: hits: $M = 1088$ ms, $SD = 252$, misses: $M = 1206$ ms, $SD = 452$; older adults: hits: $M = 1768$ ms, $SD = 496$, misses: $M = 1911$ ms, $SD = 664$, both *t*'s < 1, *p*'s > .05.

Three older participants achieved a *d´* score of 0.5 of less for items studied immediately before testing, as well as three young and four older adults for items studied 60 minutes before testing. Priming in these individuals was not significantly different to zero (means ranging from -.02 to .14, largest $t(2) = 2.5$, $p = .13$).

Table 2.4. Mean of median identification RTs for old and new items in the young and older adult groups in Experiments 2 and 3.

	Young			Older		
	Old (immediate)	Old (delayed)	New	Old (immediate)	Old (delayed)	New
Exp. 2	1116 (310)	1110 (262)	1305 (471)	1807 (598)	1784 (541)	1962 (650)
Exp. 3	1174 (349)	1221 (366)	1405 (462)	2278 (857)	2322 (372)	2471 (785)

Note. Standard deviations in parenthesis. Identification times were slower in older relative to young adults in both Experiments (all *t*'s > 4, *p*'s < .001).

2.2.3 Discussion

Recognition memory was once again reduced by age and delayed testing, but this time there were no significant effects in priming. There was, however, a clear numerical trend – priming was lower in older adults in comparison to young, and clearly not preserved in old age. There are two possible explanations for this numerical trend: First, there is a genuine decline in priming with age which this experiment failed to detect statistically. Second, priming was marginally reduced in older individuals compared to young due to explicit contamination in the priming (CID) task. As outlined in the Introduction, age effects in priming could reflect differences between groups of young and older individuals in the use of an explicit strategy. Because all participants in the CID-R task are test aware, it is possible that they adopted an explicit processing strategy in the CID portion of the trial.[3] That is, they may have attempted to think back to the prior study episode and of the objects they witnessed previously in order to facilitate their identifications of the objects. Such a strategy is likely to be more beneficial to young individuals due to their superior explicit memory, so it is possible that the numerical age difference in priming reflects the use of a recollective strategy which amplified priming in the young adult group.

In Experiment 3, the effect of age on priming was examined once more, while attempting to reduce the level of test awareness experienced by participants in the priming (CID) task (see next section). To preview, after finding that the numerical age difference in priming persisted when test awareness (and thus the likelihood of explicit processing) was reduced, we turn to the prediction that the individual experiments reported in this chapter failed to statistically detect small but real age differences in priming.

2.3 Experiment 3

An attempt was made to reduce test awareness in the priming (CID) phase, in order to limit the likelihood that participants would adopt a voluntary explicit strategy in this task. All aspects of the design and procedure were the same as in Experiment 2, except that the test phase was broken down into separate CID and recognition phases, and a post-test awareness questionnaire was introduced. It was assumed that participants would be less likely to become aware in the CID task when no reference is made to the prior study episode and when they are not required to make a recognition judgement after every identification trial. Thus, replicating the age-group trend in priming seen previously would minimise the likelihood that the effect is due to differences between groups in the successful use of and explicit strategy in the CID task.

2.3.1 Method

2.3.1.1 Participants

Eighteen young (seven male) and 18 older (two male) adults participated for payment of £5. The young adults were again recruited through the UCL participant database, and the older adults through the U3A. All were native English speakers who reported good health. Participant demographic information is given in Table 2.5.

[3] Throughout the thesis, the terms *test aware* and *aware* are used to refer to the knowledge possessed by participants that previously studied items are present at test. This can occur either because participants are informed that some items are old (as in the CID-R task) or because they spontaneously come to this realisation.

2.3.1.2 Stimuli and procedure

The same stimuli were used once more, and the experimental procedure was very similar to that in Experiment 2: there was an initial study phase, a 60 min interval, a second study phase, the CID task and finally the recognition task. Thirty pictures from each study phase later served as old items in the CID task, and an additional 30 pictures which were included in the initial study phase served as old items in the recognition task, but were not presented in the CID phase. Different critical items were presented in the CID and recognition tasks, as ceiling recognition performance was found in a pilot study that used the same items in both (as participants viewed the items twice by the time they performed the recognition task). An additional 60 pictures were presented in the CID task, and 30 in the recognition task, to serve as new items.

The experimental procedure was again around 90 minutes in duration (with breaks provided), and at the end of the experiment participants completed a questionnaire to gauge the level of test awareness experienced during the CID phase. Some have questioned the validity of post-test questionnaires in assessing subjective awareness (e.g., Reingold & Toth, 1996; but see Barnhardt & Geraci, 2008, for arguments supporting their validity), but this was deemed to be the most appropriate method of examining awareness in the present experiment. The questionnaire used was similar to that introduced by Bowers and Schacter (1990), and included the following items: (1) *What do you think was the purpose of the identification task you performed?* (2) *Do you think that any of the pictures you identified were previously presented in the first parts of the experiment?* If participants failed to notice that any of the pictures were previously studied, they were classified as unaware and were not required to complete the rest of the questionnaire. If they realised that some pictures were previously studied they were asked to complete the following questions: (3) *Were you aware that some of the pictures had been shown before as you were performing the task, or did you become aware of this afterwards/in hindsight?* (4) *Did you suspect prior to the start of the identification task that you would be tested on your memory of the pictures?* (5) *Did you try to use your memory of the pictures to help you in this task?* (6) *If yes, do you think this strategy helped you, and how so?* Participants who stated they became aware in hindsight were classified as unaware at the time of testing, and all other participants were classified as aware.

Table 2.5. Participant characteristics in Experiment 3.

	Young	Older
	(*n* = 18)	(*n* = 18)
	M (SD)	*M (SD)*
Age (years)	23.9 (3.5)	73.3 (6.7)
Education (years)	16.0 (1.6)	15.8 (1.4)
Visual acuity *	29.4 (6.9)	37.8 (8.1)
WAIS-III Vocabulary *	56.6 (8.7)	65.4 (1.1)
WAIS-III Digit Symbol *	80.5 (17.9)	64.7 (18.0)
WTAR	42.7 (5.1)	49.3 (0.7)
MMSE	-	29.7 (0.5)

Note: Scores on the MMSE ranged from 28 to 30, thus no participant neared the imposed cut off limit of 23.

* Significant difference between groups, $p < .05$

2.3.2 Results and Discussion

2.3.2.1 *Study*

Categorization accuracy was at 98.4% correct for both young and older adults on the initial study phase (young *SD* = 1.93; older *SD* = 2.25), and at 98.7% (*SD* = 2.60) for young, and 99.1% (*SD* = 1.92) for older adults on the second study phase. Performance was not statistically different between groups in either study phase (immediate study: $t(34) = 0.08$, $p = .94$; delayed study: $t(34) = 0.49$, $p = .63$. Study phase response times were significantly faster for young (*M* = 1684 ms, *SD* = 559) relative to older (*M* = 2262 ms, *SD* = 518) adults in the initial study phase, $t(34) = 3.22$, $p = .003$, $d = 1.06$, but did not differ between groups on the second study phase (young *M* = 1647 ms, *SD* = 659; older *M* = 1876 ms, *SD* = 424, $t(38) = 1.24$, $p = .22$).

2.3.2.2 Recognition

Recognition (Figure 2.5) was significantly greater than chance for young, $t(17) = 7.52$, $p < .001$, and older adults, $t(17) = 7.32$, $p < .001$. Discrimination (d') was significantly greater in young relative to older adults, $t(34) = 3.41$, $p < .002$, $d = 1.19$, but there was no significant difference in response bias between the two groups (young: $C = .35$, $SD = .53$; older: $C = .57$, $SD = .47$, $t(34) = 1.31$, $p = .20$).

2.3.2.3 Priming

A total of 261 out of 4320 trials (6.04%) across participants were removed due to incorrect identifications, etc (138 for older adults and 123 for young adults). Priming (Figure 2.5; see Table 2.4 for identification RTs) was significantly greater than zero for items studied immediately prior to testing for young, $t(17) = 2.63$, $p = .02$, and older adults, $t(17) = 2.48$, $p = .02$, and items studied 60 min prior to testing for young adults, $t(17) = 2.20$, $p = .04$. Priming for items studied 60 min before testing fell short of significance in the older adult group, $t(17) = 1.58$, $p = .06$ (one-tailed). An ANOVA revealed no significant main effect of age-group, $F(1, 34) = 1.02$, $p = .32$, or delay, $F(1, 34) = 0.62$, $p = .44$, and no significant interaction, $F(1, 34) = 0.01$, $p = .92$.

Once again young adults completed the test more rapidly than older adults: an average of 29.2 and 27.5 minutes, for young and older adults, respectively.

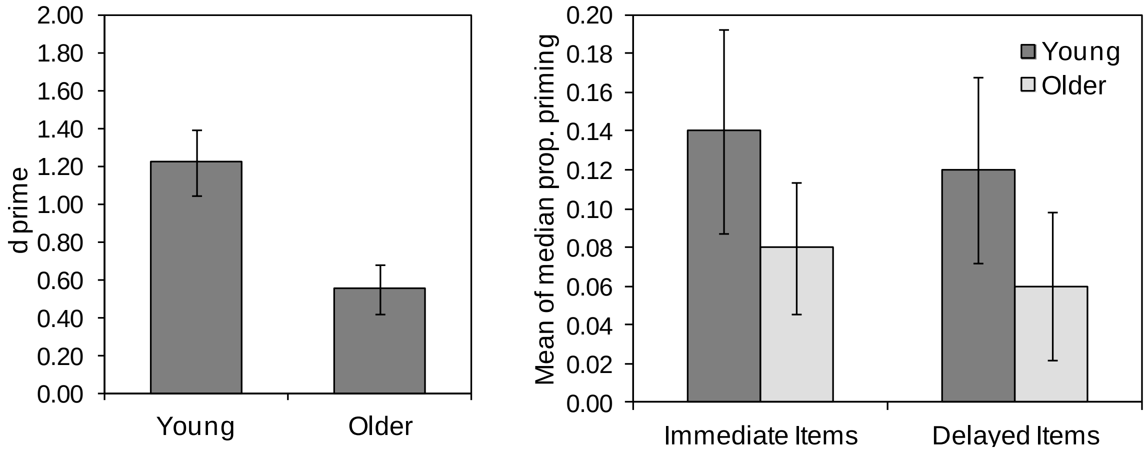

Figure 2.5. Left panel: Mean *d'* scores for young and older adults in Experiment 3. Right panel: Priming scores in young and older adults as a function of delay. Error bars represent SEM.

2.3.2.4 Post-test awareness

Ten out of 18 young participants (55.5%), and 9/18 older participants (50%), were rated as aware during the CID phase. Collapsed across immediate and delayed items, priming did not significantly differ between aware versus unaware young participants (aware $M = .12$; unaware $M = .13$, $t(34) = 0.21$, $p = .84$), or aware versus unaware older participants (aware $M = .08$; unaware $M = .08$, $t(34) = 0.14$, $p = .89$). There was also no significant difference between aware young versus older participants, $t(36) = 0.51$, $p = .61$, or unaware young versus older participants, $t(32) = 0.92$, $p = .36$. It should be noted that, because participants answered the questionnaire after the task was completed in its entirety, their recollection of the awareness experienced during the CID phase may have been distorted, and more participants may have actually been unaware during this phase than is reflected here.

2.3.2.5 Other analyses

No comparisons of RTs for recognition hits and misses were carried out because different items were used in the CID and recognition phases.

Correlations. Collapsed across age group, the correlation between *d′* scores and priming for items studied immediately before testing did not quite reach significance, r = .12, p = .53, and similarly for *d´* scores and priming for items studied 60 min before testing, r = .30, p = .08.

In sum, the results of Experiment 2 were replicated – recognition was reliably reduced as a function of age, and priming numerically lowered. To test the prediction that the age-difference in priming is genuine but failed to reach significance, statistical power was increased by pooling and re-analysing the data from the individual experiments.

2.4 Re-analysis of pooled priming data

This analysis included the priming data from Experiments 1, 2 and 3. It is important to note that no participant took part in more than one experiment. Across experiments, the priming scores of young and older individuals for immediate and delayed items were pooled (n = 58 per group). Figure 2.6 illustrates the overall age difference in priming for immediate and delayed items. Priming was significantly above chance for young adults ($t(57) = 7.29$, $p < .001$, and $t(57) = 6.44$, $p < .001$, for immediate and delayed items, respectively), and older adults ($t(57) = 5.64$, $p < .001$, and $t(57) = 5.87$, $p < .001$, for immediate and delayed items, respectively). A 3 (experiment) x 2 (age-group) x 2 (delay) ANOVA revealed significant main effects of experiment, $F(2, 110) = 7.17$, $p = .001$, $\eta_p^2 = .12$, and age-group, $F(1, 110) = 4.10$, $p = .045$, $\eta_p^2 = .04$, but no effect of delay, $F(1, 110) = 0.46$, $p = .45$, and no interactions (largest $F = 1.59$, $p = .21$). Follow-up tests confirmed that priming was significantly greater in young relative to older adults for items studied immediately before testing, $t(114) = 2.30$, $p = .02$, $d = 0.42$, but not those studied 60 minutes prior to testing, $t(114) = 0.89$, $p = 39$. Priming did not differ between Experiments 2 and 3 for items studied immediately before testing or those studied 60 min before testing (both t's < 1, p's > .60; collapsed across age-group), but priming at both intervals in Experiment 1 differed to that in Experiments 2 and 3 (largest $t = 3.07$, $p = .003$).

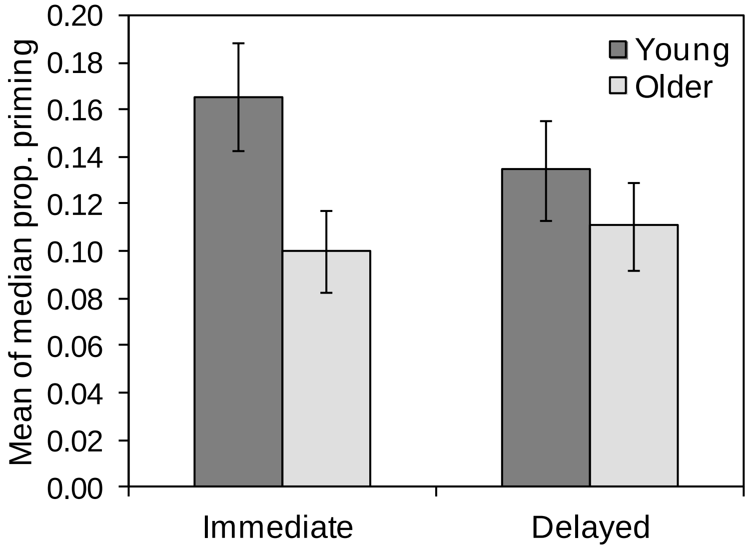

Figure 2.6. Pooled priming data for immediate and delayed items in young and older adults (*n* = 58 per group). Error bars in indicate SEM.

The critical observation is the reliable overall reduction in priming with age. This is consistent with the single-system view which predicts an age effect on priming that is weaker than that on recognition due to the lower reliability of priming measures. Reliability of the recognition and priming tasks in Experiments 1, 2 and 3 was objectively examined using split-half correlations (see Buchner & Wippich, 2000).

Measure reliability. We computed two scores for recognition (*d´*) and priming (proportion) for each participant by extracting odd and even test trials. We expected the correlation between these scores to be larger in recognition than priming, and this was observed in all cases (see Table 2.6). We also computed aggregate correlation coefficients for recognition and priming in the three experiments, and in all cases the correlation was significantly larger for the recognition scores in relation to priming (z = 4.41, p < 001, z = 2.64, p = .008, and z = 2.54, p = .01, for Experiments 1, 2 and 3, respectively). Thus, the failure of the individual experiments to detect a significant age difference in priming was likely exacerbated by the lower reliability of the priming (CID) task relative to recognition. It should be noted that these split-half correlations are merely reliability estimates, and are likely to be noisy due to the small samples. They serve to demonstrate that the priming index is statistically less reliable than the recognition measure, as predicted by the single-system model.

Table 2.6. Split-half correlations for the recognition and priming scores in Experiments 1-3.

	Experiment 1				
	Young		Older		
	Immediate	Delayed	Immediate	Delayed	Aggregate
Recognition					
r	.63	.67	.51	.54	.62
p	.003	.001	.02	.01	< .001
Priming					
r	.21	-.06	-.30	.20	-.01
p	.39	.79	.21	.40	.90
	Experiment 2				
	Young		Older		
	Immediate	Delayed	Immediate	Delayed	Aggregate
Recognition					
r	.69	.32	.69	.30	.49
p	< .001	.17	< .001	.20	< .001
Priming					
r	-.06	-.03	-.31	-.04	-.12
p	.81	.89	.19	.84	.35
	Experiment 3				
	Young		Older		Aggregate
Recognition					
r	.54		.46		.59
p	.02		.05		< .001
	Immediate	Delayed	Immediate	Delayed	
Priming					
r	.22	.51	.09	-.23	.14
p	.38	.03	.70	.35	.25

Note. The aggregate correlation coefficients were calculated by pooling the relevant individual data points. The aggregate *r* values were *z*-transformed to test the null hypothesis that *r*(recognition) – *r*(priming) = 0.

In Experiments 1, 2 and 3, young and older adults were matched on education level and pre-morbid intelligence, but differed in visual acuity (Experiments 2 and 3), processing speed, and vocabulary scores. Could these differences have contributed towards the age difference in priming? Vocabulary scores were greater in older relative to young adults (as is usually the case), thus this factor could not have contributed to the decline in priming with age. Processing speed was generally slower in older relative to young adults, and this would have likely contributed towards slower overall responding in this group. This potential confound was controlled for: a priming score was calculated for each individual in proportion to their baseline response speed, eliminating any potential gravity of longer baseline RTs in the older adult group (see section 1.3.1 for further discussion).

Between group differences in visual acuity could have contributed to the age difference in priming if, for instance, older adults' priming scores were reduced because of an impairment in their ability to see the visual stimuli (in comparison to young participants). Vision was average to above average in both groups in all experiments, so this is extremely unlikely, but nevertheless, a multiple regression was conducted to determine whether the age difference in visual acuity can explain the age difference in priming. Both age and visual acuity were used as predictors of the criterion variable priming. The overall model was significant, $F(2,115) = 3.61$, $p = .03$, however only age emerged as a significant predictor of priming, $t(113) = 2.65$, $p = .009$. Visual acuity scores did not predict variance in priming, $t(113) = 1.37$, $p = .17$. It is worth noting that while priming correlated with age, $r(113) = -.21$, $p = .01$, it did not significantly correlate with visual acuity $r(113) = .04$, $p = .32$.

2.5 Chapter Summary

The goal of the experiments presented in this chapter was to ascertain whether a measure of implicit memory function (priming) is affected by normal ageing in a similar way to explicit memory (recognition). Recognition memory was significantly reduced by normal ageing in three experiments, and priming was most often numerically lowered. However, the pooled data analysis confirmed a reliable overall reduction in priming as a function of age, with an effect of substantial magnitude (46% reduction collapsed across immediate and delayed items). This effect is of considerable theoretical importance, as outlined in the Introduction. If levels of priming were equivalent in young and older individuals, this would strongly suggest that they are driven by distinct memory systems. In contrast, the single-system view predicts that the same age effect will be observed in priming as occurs in recognition, and the analyses suggest that the effect in priming is likely to have been weaker due to the lower reliability of this measure. The results are therefore consistent with the single-system view.

Results from the item analyses in Experiments 1 and 2 also support the single-system view. Identification latencies for recognition hits were consistently faster than latencies for recognition misses, and in many cases this difference was significant. If priming and recognition are driven by independent implicit and explicit memory systems, then identification latencies should be equivalent for all old for items regardless of whether or not they are subsequently recognised. Furthermore, priming was reduced to zero in the small subset of individuals who obtained very low recognition scores, providing evidence against the independence of explicit and implicit forms of memory.

The delay effects on recognition and priming are also more compatible with the single-system than the multiple-systems view. In most cases the effect of delay on recognition was either statistically very weak or non-significant, illustrating the small magnitude of the effect. Priming was generally unaffected by the delay, but the small effect size coupled with the lower reliability of the CID task renders this not surprising. In most cases there was a numerical effect of delay on priming which mirrored that in recognition, meaning that it would be difficult to strongly interpret this finding as support for multiple memory systems.

Older adults were generally slower at completing the CID-R task relative to young adults, and one must consider the implications of this. Identification times were generally slower in older adults, and one may presume that this group also spent longer typing the object names into the keyboard on each trial (although there are no data to confirm this). The discrepancy in the total test-phase duration (although relatively minor) may mean that memory for previously studies items was slightly weaker in older adults, particularly for those presented towards the end of the test phase. However, because trials were randomised for each participant, one may argue with a fair amount of confidence that, although the priming and recognition data for older adults may have slightly noisier, the difference in the total time taken is not a factor that should cause significant concern.

The conclusion that priming is reduced in normal ageing rests crucially on eliminating the possibility that the priming measure was contaminated by explicit processing. As outlined previously, explicit processing in the CID task could be of a greater benefit to the performance of young adults, and could explain the age effect obtained on this measure. Test awareness is a necessary condition for the use of an explicit strategy, and in Experiment 3 awareness was reduced by separating the priming and recognition tasks. The numerical age-related reduction in priming persisted when the data from test aware participants were removed, thus it seems unlikely that the age effect in priming was driven by explicit contamination. Nevertheless, in Chapters 3 and 4 I consider in more depth the influence of test awareness and explicit processing on the magnitude of priming in the CID task, in order to gain a better view as to whether this task is susceptible to explicit contamination which can lead to enhanced priming in young individuals.

Chapter 3: Test Awareness and Priming in the CID-R Paradigm

The focus of Chapter 3 is on the relationship between test awareness and priming in the CID-R task. The question of interest is whether the test awareness that is associated with this task has an effect on the magnitude of priming obtained, through encourageing participants to adopt a voluntary explicit strategy. In three experiments I manipulated the likelihood that participants would become test aware during the CID task, and evaluated the effect on priming. Before describing the experiments, a more extensive literature review on the topic of explicit contamination is provided.

MacLeod (2008) reviewed a range of measures that have been used to circumvent explicit contamination in priming tasks, which typically involve reducing test awareness. However, as outlined in the Introduction, a valuable and contemporary method of studying the relationship between explicit and implicit memory is to measure the two concurrently, such as in the CID-R task. Because participants in this task are necessarily test aware, it is important for researchers who employ this measure to consider the potential impact this has upon priming. Priming in the CID task is usually measured by response latencies, and it has been suggested that explicit processing is unlikely to occur under these circumstances because identification is usually accomplished too quickly for the engagement for explicit memory strategies (see MacLeod, 2008). To , knowledge this has never been tested empirically, and one could imagine several ways in which the use of explicit processing could affect priming calculated from response times. For instance, if test awareness encourages participants to engage in a search of explicit memory during the CID task, this could feasibly speed up identifications of old items, or slow down identification times for new items – both of which would lead to an inflated priming score.

Although there has been a limited focus on the impact of test awareness and explicit processing on priming in the CID-R task, several studies have examined the problem using other priming tasks. This has typically involved an instructional manipulation of test awareness, where some participants are informed about the nature of the task and others perform it under standard implicit instructions. Bowers and Schacter (1990) found no difference in priming between informed and uninformed participants on a word-stem completion task, and no interaction with a levels-of-processing manipulation; however priming was greater in uninformed participants who spontaneously became test aware relative to those who did not (Experiment 1). In a similar study that also used a word-stem completion task, Mace (2003) reported enhanced priming in informed relative to uninformed participants for items studied under semantic but not nonsemantic conditions. Of relevance to the CID-R task, Brown, Jones, and Mitchell (1996) found that priming did not differ when identification and recognition judgements were presented concurrently on every trial relative to separate experimental phases, suggesting that the presence of the recognition task alongside priming on every trial, which arguably induces greater test awareness than when the tasks are separated, does not affect priming (see also Stark & McClelland, 2000). One caveat in these studies, however, is that participants in uninformed groups may still have experienced test awareness, and this was neither measured nor controlled for. In the present experiments I monitored test awareness in the various 'low awareness' conditions by administering the post-test awareness questionnaire described previously.

To be able to evaluate the effects of test awareness on priming, one must strive to obtain an adequate 'unaware' control group for comparison purposes. This means rigorously concealing the fact that previously studied items are present at test. One way of doing this is to vary the ratio of old and new items in the testing phase (see Jacoby, 1983; Richardson-Klavehn, Lee, Joubran, & Bjork, 1994). When only a small proportion of trials are old, participants are less likely to notice the connection between the study and test phases and are thus less likely to be inclined to adopt an explicit retrieval strategy in comparison to participants who are test aware. A handful of prior studies have employed this method of varying test awareness, but because this has typically been done to bolster an instructional manipulation (i.e., informed participants are exposed to a high proportion of old trials and uninformed participants are exposed to a low proportion of old trials), it is impossible to unravel the differential contributions of the factors to the results. Jacoby (1983) reported enhanced priming on a word naming task in informed participants who witnessed 90% old trials at test relative to uninformed participants who were exposed to 10% old trials (see also Richardson-Klavehn et al., 1994).

In Experiments 4, 5 and 6 of the present thesis, I manipulated test awareness in young individuals by varying task type (CID versus CID-R), and the proportion of old trials at test (low versus high). Participants are less likely to become test aware in the CID relative to the CID-R task (around 50% of participants rated themselves as test unaware on this task in Experiment 3), and it was assumed this will also be the case when they witness a low relative to a high proportion of previously studied trials at test. Priming was compared in test aware and test unaware participants, with the view that this would aid in the interpretation of the age effect in priming observed in Chapter 2: If different states of test awareness mediate differences in priming, then it is conceivable that the age difference in priming was driven by explicit contamination. Even though both the young and older adult groups in Experiments 1 and 2 would have been test aware during the CID-R task, the young individuals may have been more likely or better able to engage in a successful explicit strategy relative to older adults. On the other hand, if differences in test awareness do not affect priming, then this would suggest that the age difference in priming is not due to explicit contamination.

3.1 Experiment 4

Priming in young individuals on the CID-R task (which induces test awareness) was compared to that in the purer CID task in which participants are less likely to become aware. If awareness enhances priming then one would expect to find greater overall levels of priming in the CID-R relative to the CID task. The ratio of old to new items at test was also varied. Participants were either exposed to a low proportion of old trials (20% old and 80% new) or to a high proportion of old trials (80% old and 20% new), with the assumption that this would create further differences in test awareness in the CID task. That is, witnessing a high proportion of old items at test should induce greater test awareness relative to a low proportion of old items because participants are more likely to notice that items were presented at study. There were four conditions in total: CID Low, CID High, CID-R Low, and CID-R High. Because the CID-R task induces awareness, one would not expect the CID-R Low and CID-R High groups to differ. In contrast, if awareness affects priming then one would expect more priming in the CID High relative to the CID Low condition, as the latter is the least likely to induce test awareness in participants.

3.1.1 Method

3.1.1.1 Design and participants

Eighty students from UCL (29 male) with an overall mean age of 21.9 years (*SD* = 2.1) took part in the experiment for course credit or payment of £4. All were native English speakers with normal or corrected vision. The experiment used a 2 (CID vs. CID-R task) x 2 (low vs. high proportion old trials) between-subjects design, and participants were split equally between the four conditions.

3.1.1.2 Stimuli and procedure

The stimuli were the same as those used previously. All participants witnessed 120 pictures at study, all of which served as old items at test in the High groups (interspersed among 30 new items), and 30 of which served as old items at test in the Low groups (among 120 new items). Five 30-item sets of pictures were rotated between participants to counterbalance those serving as old and new items.

The procedure for the study phase, CID and CID-R tasks was identical to that described previously. All participants performed the study phase followed by either the CID or CID-R task with either a low or high proportion of old item trials. Thus, the CID Low and CID High conditions, and the CID-R Low and CID-R High conditions, only differed with respect to the different proportions of old item trials at test. Participants in the CID groups performed the task under standard implicit instructions – at test they were asked to identify masked pictures as quickly as possible, and no reference was made to the prior study episode. In the CID-R conditions, the nature of the test phase instructions meant that participants were aware that some items had been previously studied – they were asked to identify masked pictures as quickly as possible and state whether they believed each was shown at study – but they were not informed of the ratio of old/new trials. The experimental duration was approximately 30 minutes, and participants in the CID groups completed the awareness questionnaire (described in Chapter 2) at the end of the experiment.

3.1.2 Results and Discussion

3.1.2.1 Study

Categorization accuracy ranged from 96.9% to 98.4% and performance did not significantly differ between groups, $F(3, 76) = 1.31$, $p = .28$. Study phase RTs ranged from 1264 (SD = 154) to 1455 ms (SD = 359) and speed did not significantly differ between groups, $F(3, 76) = 1.41$, $p = .34$.

3.1.2.2 Recognition

Item discrimination (d'; Figure 3.1) was significantly greater than chance in the CID-R Low group, $t(19) = 12.50$, $p < .001$, and CID-R High group, $t(19) = 18.13$, $p < .001$, and performance was not significantly different between groups, $t(38) = 1.30$, $p = .20$. There was no significant difference in response bias between the CID-R Low (C = -.12, SD= .40) and CID-R High (C = .09, SD= .59) groups, $t(38) = 1.24$, $p = .22$.

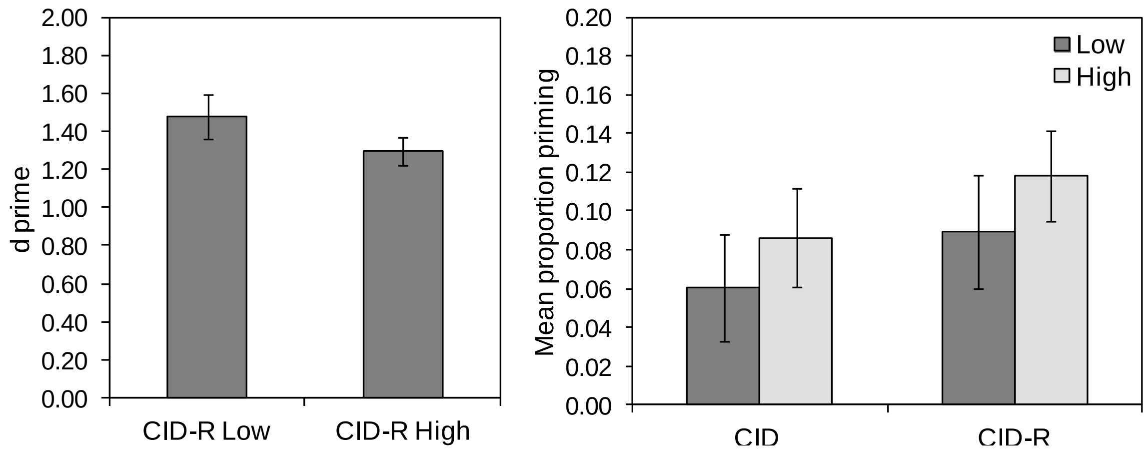

Figure 3.1. Left panel: Mean *d'* scores for the CID-R Low and CID-R High tasks in Experiment 4. Right panel: Priming in the CID Low, CID High, CID-R Low and CID-R High conditions. Error bars indicate SEM.

3.1.2.3 Priming

Priming was calculated using the same method described in Chapter 2, but because of the problems associated with using medians when there are unequal numbers of old and new test trials (see Miller, 1988), calculations were based on mean identification times. Mean RTs were positively skewed, so we repeated the analyses on the log transformed data. Both methods yielded a consistent result, so we report analyses of priming scores derived from mean RTs. Across conditions, a total of 637 out of 12000 trials (5.30%) were removed due to incorrect identifications etc (165 from the CID Low condition, 159 from CID High, 142 from CID-R Low, and 171 from the CID-R High condition).

Priming was significantly above zero in all groups (all t's > 2, p's < .05). Priming was numerically greater in the CID-R relative to CID tasks, and in the conditions with a high relative to a low proportion of old trials (Figure 3.1; See Table 3.1 for identification RTs), but there was no significant main effect of task, $F(1, 76) = 1.30$, $p = .26$, or of the proportion of old trials, $F(1, 76) = 1.10$, $p = .30$), and no significant interaction, $F(1, 76) < 0.01$, $p = .95$.

Table 3.1. Identification RTs for old and new items in Experiments 4, 5 and 6

	Old *M (SD)*	New *M (SD)*
Experiment 4		
CID Low	1325 (327)	1423 (351)
CID High	1123 (421)	1234 (404)
CID-R Low	1349 (496)	1473 (424)
CID-R High	1368 (296)	1577 (420)
Experiment 5		
First test		
CID	1268 (521)	1410 (531)
CID-R	1505 (812)	1679 (755)
Second test		
CID	1161 (553)	1253 (567)
CID-R	1312 (344)	1590 (385)
Experiment 6		
First block		
Low	1139 (309)	1391 (377)
High	1279 (369)	1578 (479)
Second block		
Low	1221 (411)	1523 (503)
High	1087 (299)	1212 (329)

Note. Mean of mean identification RTs are listed for Experiments 4 and 6, and mean of medians for Experiment 5.

3.1.2.4 Post-test awareness

All participants in the CID High condition, and 12/20 (60%) in the CID Low condition, were deemed test aware at the time of testing. Of the latter, priming did not reliably differ between aware and unaware participants (aware: M = .09, SD = .12; unaware: M = .05, SD = .13; $t(18) = 0.77$, p = .45).

In sum, priming did not significantly differ among the conditions assumed to induce different states of test awareness, nor between participants who became test aware and those who did not. If test awareness affects priming, then one would expect priming to be similar in the CID-R Low, CID-R High, and CID High conditions (all of which induce awareness) in comparison to lower priming in the CID Low condition, but this was not the case. The findings suggest that test awareness does not influence priming in this paradigm, or that any such effect is quite small. Between-group variability undoubtedly limited the power of this experiment to detect small differences in priming, so additional experiments were conducted to explore the manipulations of task (CID versus CID-R; Experiment 5) and the different ratios of old/ new test items (low versus high; Experiment 6) using within-subjects designs.

3.2 Experiment 5

Priming in young adults on the CID-R and CID tasks was compared. A within-subjects design was used and test order was rotated between participants – half performed the low awareness condition (CID task) first and the high awareness condition (CID-R task) second, and vice versa for the other half. If awareness enhances priming then one would expect to find greater priming in the CID-R relative to the CID task and expect this to interact with test order. That is, the condition in which the CID task is presented first is the only true 'low awareness' condition, and thus the only instance in which one might expect reduced priming in comparison to the CID-R task. One would not expect priming to be lower in the CID task when it is presented second (following the CID-R task) because participants will have become test aware by this point.

3.2.1 Method

3.2.1.1 Participants

Forty students from UCL took part in the experiment for course credit or payment of £4. There were 24 females and 16 males with an overall mean age of 22.6 years (*SD* = 3.2). All were native English speakers with normal or corrected vision. Participants were split equally between the two test order conditions.

3.2.1.2 Stimuli and procedure

The same stimuli were used once more, and the procedures for the study phase, CID, and CID-R tasks were as outlined previously. Eighty pictures were presented at study, and 80 in each test (CID and CID-R), comprised of 40 old and 40 new items. To achieve counterbalancing among old/new items, four 40-item sets of pictures were rotated between participants. The test phase began with the CID task for half the participants, and with the CID-R task for the other half. After the first task, participants were immediately given instructions for the second. The experiment lasted approximately 30 minutes, and participants who performed the CID task first were given the awareness questionnaire at the end of the session. Participants who performed the CID task second were deemed test aware.

3.2.2 Results and Discussion

3.2.2.1 Study

Categorization accuracy was at 95.4% (*SD* = 2.1) and 96.8% (*SD* = 2.0) in the CID task first and CID-R task first conditions, respectively. Although the study phase task was identical in the two groups, performance was statistically superior in the latter, *t*(38) = 2.12, *p* = .04. Incorrect study phase trials were removed from all further analyses, meaning that slightly more data were lost in the condition in which the CID task was presented first, but the total loss was very low in both cases. Study phase response times did not differ between the two groups (CID task first *M* = 1244, *SD* = 279; CID-R task first *M* = 1324, *SD* = 242, *t*(38) = 0.96, *p* = .34).

3.2.2.2 Recognition

Recognition (*d'*; Figure 3.2) was significantly greater than chance in both conditions (CID-R task first: *t*(19) = 10.13, *p* < .001; CID-R task second: *t*(19) = 11.30, *p* < .001). Performance was reliably greater when the CID-R task was presented first as opposed to second, *t*(38) = 2.57, *p* = .01, *d* = 0.52, presumably reflecting normal memory decay over time. There was no significant difference in response bias between the two conditions (CID-R block first: *C* = .07, *SD*= .26; CID-R block second: *C* = .31, *SD*= .43; *t*(38) = 1.75, *p* = .09).

3.2.2.3 Priming

Across conditions, a total of 327 out of 7200 trials (5.30%) were removed due to incorrect identifications etc (169 from the CID task first condition, and 158 from the CID-R task first condition). Priming (Figure 3.2; see Table 3.1 for identification times) was significantly greater than chance in both tests, in both conditions (all *t*'s > 1, *p*'s < .05). There was no main effect of task, *F*(1, 38) = 0.05, *p* = .82, or test order, *F*(1, 38) = 1.83, *p* = .13, and no interaction, *F*(1, 38) = 2.65, *p* = .11, thus there is no evidence that awareness affects priming. Priming was identical in the CID and CID-R tasks when they were each presented first (*M* = .10), and although awareness would have been greater in the CID task when it followed CID-R relative to when it was presented first, priming was actually lower in the former case (.06 versus .10). In the second tests, the magnitude of priming was numerically (but not statistically, $t(38) = 1.50$. $p = .14$) greater in the CID-R relative to the CID task, but it is unlikely that the trend is related to test awareness as all participants would have become aware by the time they performed the second test.

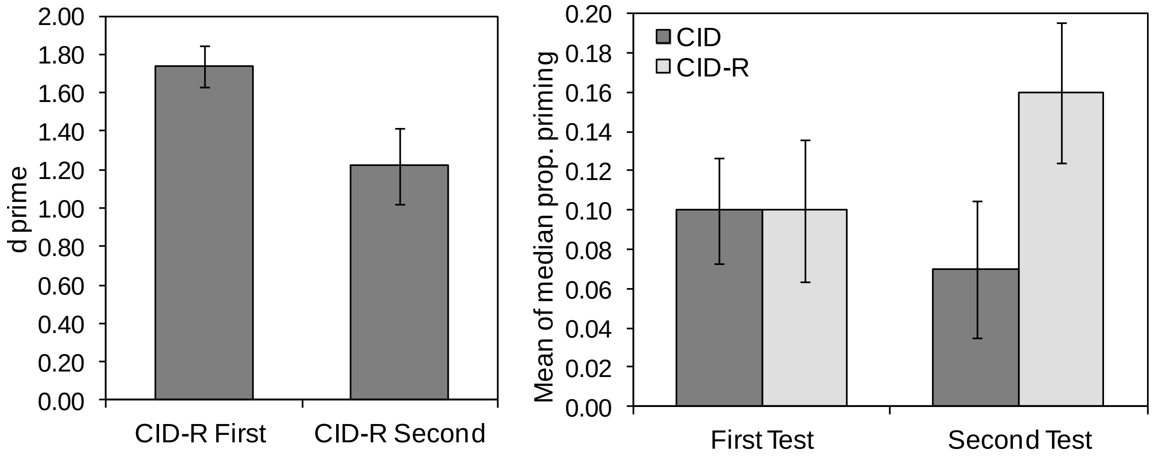

Figure 3.2. Left panel: Mean *d'* scores for the two CID-R tests (first and second) in Experiment 5. Right panel: Priming in the first and second CID and CID-R tasks. Error bars represent SEM.

3.2.2.4 Post-test awareness

Of the participants who performed the CID task first, 9/20 (45%) were rated as test aware during this task. Priming in this subset of individuals was actually elevated in comparison to that of participants classed as unaware, but not significantly so (unaware: *M* = .11; aware: *M* = .09, $t(16) = 0.46$, $p = .65$).

To summarise, the critical observation is that priming did not reliably differ between the CID and CID-R task conditions, or between aware and unaware participants who performed the CID task first.

3.3 Experiment 6

The aim of Experiment 6 was to further examine the effect of varying the proportion of previously studied trials at test. Using a similar design to Experiment 5, participants performed a CID task which was broken down into two blocks containing different ratios of old to new trials – low (20% old versus 80% new) and high (80% old versus 20% new).

Half the participants performed the low block first and the high block second, and vice versa for the other half. It was anticipated that states of awareness would differ in the two conditions such that participants who performed the low block first and the high block second would become test aware at a much later stage of the test (i.e., in the second block) relative to participants who performed the high block first and the low block second. Thus, if test awareness affects priming then the magnitude of priming should be greater in the high relative to the low block in the condition in which the low block is presented first.

3.3.1 Method

3.3.1.1 Participants

There were 30 participants in total (20 female), with a mean age of 22.3 years (*SD* = 3.6). All were native English speaking students from UCL, with normal or corrected vision. Participants were split equally between the two block order conditions.

3.3.1.2 Stimuli and procedure

Eighty pictures were presented at study, and 160 in the test phase. The test phase was broken down into two blocks of 80 trials. In the low block there were 16 old-item trials interspersed among 64 new-item trials, and in the high block there were 64 old trials and 16 new trials. Following the study phase, the test phase began with the low block for half the participants and with the high block for the other half. The transition from the first to the second block was not made apparent, such that participants who performed the low block first would gradually become test aware as they entered the high block, and participants performing the high block first would become test aware very early on in the task. The experiment took approximately 25 minutes to complete, and participants were given the awareness questionnaire at the end. Item 3 on the questionnaire was modified to gauge at what point during the experiment participants became test aware: (3) *Please state approximately how far into the identification task you noticed that some pictures had been shown in the first part of the experiment, or indicate if you became aware of this afterwards/in hindsight?*

3.3.2 Results and Discussion

3.3.2.1 Study

Categorization accuracy was at 95.8% (*SD*= 4.0) in the low block first condition and 97.9% (*SD*= 2.33) in the high block first condition. Performance was marginally superior in the latter group, $t(38) = 2.04$, $p = .048$, meaning that slightly more data were lost in the condition in which the Low block was presented first due to the removal of incorrect study phase trials from subsequent analyses. Study phase response times did not differ between the two groups (Low block first *M* = 1279, *SD* = 323; High block first *M* = 1475, *SD* = 341, *t*(38) = 1.86, *p* = .07).

3.3.2.2 Priming

The priming data are presented in Figure 3.3 (see Table 3.1 for RTs). A total of 287 out of 7200 trials (3.98%) were discarded due to incorrect identification etc (161 in the Low block first condition, and 126 in the High block first condition). Priming was significantly greater than zero in both blocks, in both conditions (all *t*'s > 2, *p*'s < .05). There was no main effect of the different proportions of old trials in the test blocks, *F*(1, 38) = 2.49, *p* = .12, no main effect of block order, *F*(1, 38) = 0.88, *p* = .35, and no significant interaction, *F*(1, 38) = 1.37, *p* = .25.

Priming was equivalent in the low and high blocks when they were each presented first (both around .17), and in the second blocks priming was actually lower in the high relative to the low condition (but not significantly so, *t*(38) = 1.54, *p* = .13), thus, there is no evidence that priming was boosted by test awareness as manipulated by varying the ratio of old to new items at test.

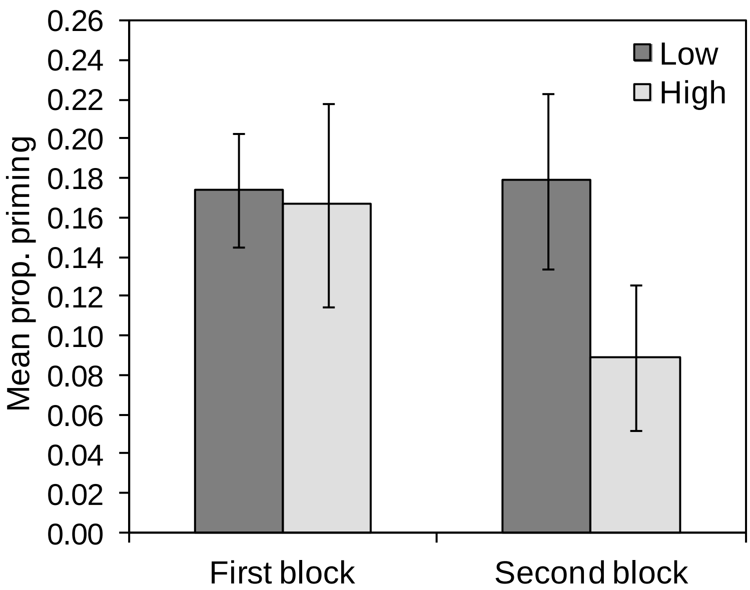

Figure 3.3. Priming in the low and high CID test blocks in Experiment 6. Error bars represent SEM.

3.3.2.3 Post-test awareness

All participants who performed the high block first indicated that they became test aware early on in the experiment. Of the participants who performed the low block first, 7/20 (35%) were classed as unaware during this block (this was based on participants rating themselves as unaware until at least half way through the test phase), but all participants indicated that they became test aware by the end of the experiment. Priming did not differ between unaware (M = .16, SD = .12) and aware (M = .18, SD = .14) participants, $t(18)$ = 0.25, p = .81).

In sum, priming was unaffected by differences in test awareness as manipulated by varying the proportion of previously studied items at test.

3.4 Chapter Summary

Three experiments provide evidence that different states of test awareness do not affect the magnitude of priming obtained on the CID task. Many participants became test aware in this task even in the low awareness conditions, but it is concluded that test awareness either does not promote explicit processing in this task, or that explicit processing does not affect the magnitude of priming observed. The findings go some way towards ruling out the possibility that the age effect in priming reported in Chapter 2 was driven by explicit contamination. Because differences in test awareness did not mediate priming in young individuals, and because such differences segregate explicit strategy use, this suggests that potential differences between young and older adults in the use of explicit processing in the priming task are unlikely to have been the main driver of the age difference in priming. However, these conclusions are limited because it is unclear whether the test awareness manipulations successfully induced participants to use an explicit strategy. In Chapter 4 I examined whether explicit processing affects priming in the CID task by providing optimal conditions for the use of an explicit strategy.

Chapter 4: Explicit Processing and Priming in the CID-R Paradigm

The effects of explicit processing on priming in the CID task were investigated further. In 4 experiments, optimal conditions for the successful use of an explicit strategy were created – namely, participants were informed prior to each CID trial whether the next item to be identified was previously studied or new, and encouraged them to use this information to help identify the object. The information provided to participants about the items enabled them to search memory of the previously studied items on appropriate trials (i.e., only on trials cued 'old'), and the effect on identification latencies and subsequent priming was of primary interest. A similar approach was used by Brown, Nesblett, Jones, and Mitchell (1991), who found no difference in priming on picture and word naming tasks between participants who witnessed old and new trials in separate blocks at test and were informed which block contained which type of item, versus a group who were uninformed and witnessed interspersed old and new trials within the test phase. However the usefulness of their uninformed group as an 'unaware' comparison condition is questionable since participants in this group may have become test aware and used explicit processing. Although the opportunity for explicit processing would have been greater in informed participants who were also advised which items were old and new, a better comparison condition would have been an uninformed group who had a limited opportunity to engage in explicit processing, and who were rigorously monitored for spontaneous test awareness. A comparison of this sort was undertaken in the present Experiment 7.

4.1 Experiment 7

One group of participants (Informed group) were told before each CID trial whether the next item to be identified was old or new, while an Uninformed group received no such information. If explicit processing enhances priming then one would expect to see greater priming in the former group because these participants are provided with sufficient information to enable them to explicitly search memory of the previously studied items on appropriate trials and make more rapid identifications.

The ratio of old to new test trials was also varied – half the participants in both groups were exposed to a high proportion of old trials (80% old and 20% new) and half to a low proportion (20% old and 80% new) with the assumption that this would create further differences in test awareness in the Uninformed group. Thus, there were 4 conditions in total: Informed Low, Informed High, Uninformed Low, and Uninformed High, and the Uninformed Low condition was deemed to be a suitable ‘unaware’ group against which to compare priming in the other groups. A main effect of informing participants would indicate an effect of explicit processing on priming, but this account would not predict a main effect of proportion. All participants in the Informed group – whether exposed to a high or low number of old trials – are test aware and equally capable of successfully using an explicit strategy, so an interaction between the factors whereby the effect of proportion is only significant in the Uninformed group (with lower priming in the low relative to the high condition) would be required to conclude that explicit processing affects priming.

4.1.1 Method

4.1.1.1 Participants and design

107 first year undergraduate students from UCL participated to fulfil a course requirement. There were 24 males and 83 females with an overall mean age of 18.7 (*SD* = 0.8). The experiment used a 2 (informed vs. uninformed) x 2 (low vs. high proportion old trials) between-subjects design, and participants were randomly allocated to one of the four conditions – Informed Low (*n* = 27), Informed High (*n* = 26), Uninformed Low (*n* = 27), Uninformed High (*n* = 27).

4.1.1.2 Stimuli and procedure

Participants were tested during a research methods practical class, but all were tested in individual computer cubicles, and there was no opportunity for participants to discuss the study before it was completed. 120 pictures were presented at study and 150 in the CID phase. In the high conditions, all the pictures presented at study were shown again at test (old items), along with an additional 30 new items. In the low conditions, only 30 old items were presented at test, along with 120 new items. Five sets of 30 items were rotated between participants to serve as old/new items.

The study phase was the same as described previously. The procedure for the CID task was also as outlined earlier, with the exception that, for participants in the Informed groups, the word ‘OLD’ or ‘NEW’ was presented at the centre of the screen for 2000 ms prior to the start of each trial, thus informing participants whether the item to be identified was previously studied or new. Participants were instructed to try to use these cues to help them identify the objects. Participants in the Uninformed groups witnessed a fixation cross for 2000 ms prior to the start of each trial, and were not informed that some items were previously studied. The experiment took approximately 25-30 minutes to complete, and participants in the Uninformed group were given the awareness questionnaire at the end of the experiment.

4.1.2 Results and Discussion

4.1.2.1 Study

Categorization accuracy ranged from 97.7% (*SD*= 2.7) to 98.3% (*SD*= 1.8), and performance did not significantly differ between groups (all *t*'s < 1, *p*'s > .05). Study phase RTs ranged from 1318 ms (*SD* = 210) to 1374 ms (*SD* = 376) and speed did not significantly differ between groups, $F(3, 76) = .16$, $p = .92$.

4.1.2.2 Priming

A total of 1074 out of 16050 trials (6.69%) were removed due to incorrect identification etc (250 in the Informed High group, 283 in the Informed Low group, 267 in the Uninformed High group, and 274 in the Uninformed Low group). Priming (Figure 4.1; see Table 4.1 for RTs) was significantly greater than chance in all groups (all *t*'s > 2, *p*'s < .05). A two-way ANOVA indicated no main effect of informing participants, $F(1, 103) = 0.11$, $p = .74$. This provides compelling evidence that explicit processing does not affect priming, as informing participants which items were previously studied provides excellent conditions for the successful use of an explicit strategy. The main effect of varying the ratio of old to new trials was significant, $F(1, 103) = 4.02$, $p = .05$, $\eta^2_p = .04$, but there was no interaction between the factors, $F(1, 103) = 0.01$, $p = .92$. It seems likely that the effect of proportion was driven by something other than test awareness. Both the Informed Low and Informed High groups were test-aware, so an interaction between the factors whereby the low and high conditions only differed in the Uninformed group is required to conclude that the effect is mediated by awareness. A comparison of priming in the Uninformed Low and Uninformed High conditions revealed no significant difference, $t(52) = 1.25$, $p = .22$. Notably, the comparison between the Informed Low and Informed High conditions revealed no significant difference, $t(51) = 1.64$, $p = .11$, so the effect is very small. (The proportion effect is examined further in Experiment 10.)

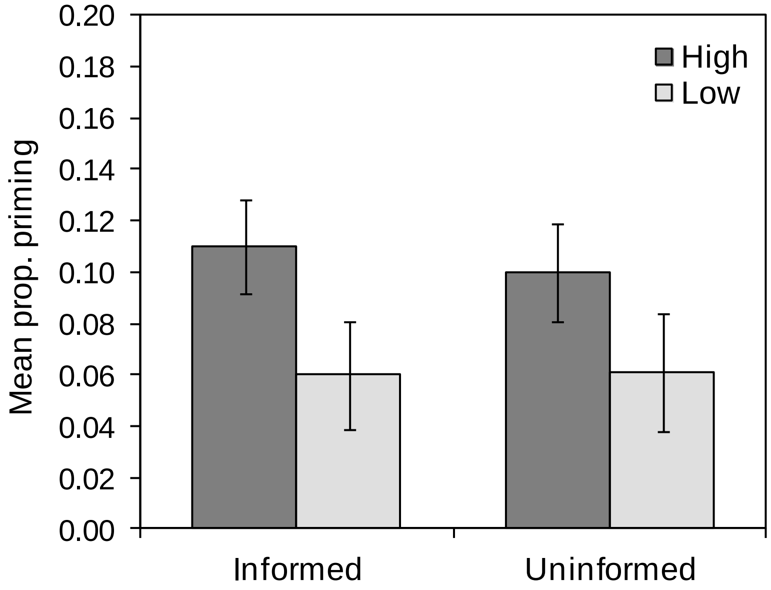

Figure 4.1. Priming in the Informed High, Informed Low, Uninformed High, and Uninformed Low groups in Experiment 7. Error bars indicate SEM.

4.1.2.3 Post-test awareness

Of the participants in the Uninformed groups, 25/27 (92.6%) in the High condition, and 14/27 (51.9%) in the Low condition reported being aware that some pictures were previously studied at the time of testing. Priming in these participants did not significantly differ to that in unaware participants (high: aware M = .09, unaware M = .11, $t(25) = 0.18$, $p = .86$; low: aware M = .06, unaware M = .05, $t(25) = 0.33$, $p = .74$).

Overall, the results suggest that orientation to explicit memory does not affect the magnitude of priming in the CID task. Identification times were very similar in the Informed and Uninformed groups, suggesting that providing participants with information to enable them to use explicit processing in this task did not affect response speed.

Table 4.1. Identification RTs for old and new items in Experiments 7 and 8.

	Old *M (SD)*	New *M (SD)*
Experiment 7		
Informed High	1479 (375)	1665 (447)
Informed Low	1652 (303)	1757 (236)
Uninformed High	1512 (292)	1677 (316)
Uninformed Low	1667 (348)	1767 (292)
Experiment 8		
Informed	1717 (470)	1897 (469)
Uninformed	1735 (331)	1937 (346)

Note. Figures represent mean of mean identification RTs in Experiment 7 and mean of medians in Experiment 8.

4.2 Experiment 8

In this experiment, the opportunity for explicit processing in the CID task was made even more salient for informed participants. Informed and Uninformed groups of participants performed a CID task with an equal number of old and new trials, but this time participants in the Informed group were also given category information ahead of each old trial (e.g., 'OLD – ANIMAL'; on new trials participants were just prompted with the word 'NEW'). Thus, on old trials, informed participants were guided to explicitly search memory of a particular (small) set of previously studied items, which arguably provides the best possible opportunity for them to produce a rapid identification time.

4.2.1 Method

Thirty two UCL students (16 in each the Informed and Uninformed groups) participated for a small payment. There were 11 males and 21 females with an overall mean age of 22.7 years (*SD* = 3.3). There were 60 critical study trials and 120 test (CID) trials (60 old and 60 new). In this experiment items corresponded to six object categories (animals, clothing, electrical appliances, fruit and vegetables, kitchen utensils and furniture), and in both conditions ten items within each category were previously studied and ten were new. Two sets of items were rotated between participants. The procedure was identical to that in

Experiment 7, except that participants in the Informed group were also given a category cue prompt in advance of old trials (e.g., ‘OLD – ANIMAL’).

4.2.2 Results and Discussion

4.2.2.1 Study

Categorization accuracy was at 95.7% (*SD*= 4.8) in the Informed group and 97.7% (*SD*= 2.1) in the Uninformed group. Performance did not significantly differ between groups, $t(30) = 1.51$, $p = .14$. Mean response times were 1102 ms (*SD* = 242) in the Informed group, and 1115 ms (*SD* = 216) in the Uninformed group, and did not significantly differ between groups, $t(30) = .16$, $p = .87$.

4.2.2.2 Priming and post-test awareness

217 out of a total 3840 trials (5.65%) were discarded due to incorrect identification etc (98 in the Informed group, and 119 in the Uninformed group). Priming (Figure 4.2; see Table 4.1 for RTs) was significantly greater than chance in both groups (both *t*’s > 3, *p*’s < .01), but did not differ between groups, $t(30) = 0.26$, $p = .79$. Of the participants in the Uninformed group, 8/16 (50%) were classed as test aware, but priming did not significantly differ between aware and unaware participants (aware $M = .10$, unaware $M = .11$, $t(14) = 0.48$, $p = .64$).

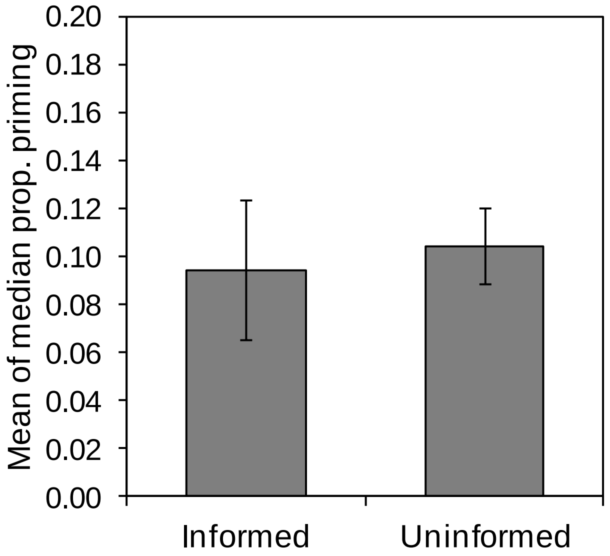

Figure 4.2. Priming in the Informed and Uninformed groups in Experiment 8. Error bars indicate SEM.

Once again, the results suggest that explicit processing during the CID task does not affect the speed of identification of previously studied items, or the magnitude of priming observed. Even with a cue that should have created a small search set in explicit memory, no benefit to identification speed was observed.

Experiment 9 investigated whether receiving incorrect as well as correct explicit information about test items affects identification speed. So far in this chapter we have seen that providing old/new status and category information about items yields no speeding of RTs or enhancement of priming relative to uninformed conditions, but a stronger test is to compare a correctly informed condition with a misinformed condition. If explicit processing can affect priming (and is responsible for the age effect obtained in Chapter 2) then one would expect that providing a cue (such as 'old' before an old picture) should induce particularly faster identifications compared to a misinformed condition (such as 'new' before an old picture) in which the participant would be discouraged from engaging in a search of explicit memory.

4.3 Experiment 9

Identification times in the CID task were compared in two groups of participants who were correctly informed about the majority of items but misinformed about the status of a subset of items. Participants were given an 'old/new' prompt before each trial, but one group was falsely informed that 30 (out of 60 total) new items were old (Misinformed-New group), and the other that 30 (out of 60 total) old items were new (Misinformed-Old group). (It is important that the majority of items were correctly cued as this ensures the overall validity of the cue.) If explicit processing can affect the rate of identification of previously studied items, then one would expect RTs for items correctly cued to differ from those incorrectly cued in both conditions (e.g., one may expect to see slower identification times for old items that participants in the Misinformed-Old group are led to believe are new, in comparison to correctly cued old items).

4.3.1. Method

4.3.1.1 Participants

There were 32 participants equally divided into the Misinformed-New and Misinformed-Old groups. All were students from UCL who participated for a small payment. There were 15 males and 17 females with an overall mean age of 22.9 years (*SD* = 3.6).

4.3.1.2 Stimuli and procedure

In total there were 60 study trials and 120 CID trials (60 old and 60 new). The stimuli and object categories were the same as those in Experiment 8. In the CID phase, participants were prompted before each trial with the word ‘OLD’ or ‘NEW’ as described previously, but both groups received incorrect information on 30 of the 120 test trials. Participants in the Misinformed-New group were informed that 30 new items were old, and participants in the Misinformed-Old group were informed that 30 old items were new. Four sets of 30 items were rotated between participants to serve as old/new pictures. The experimental duration was approximately 25 minutes.

4.3.2 Results and Discussion

4.3.2.1 Study

Categorization accuracy did not significantly differ between the Misinformed-New (M = 95.8%; SD= 3.9) and Misinformed-Old (M = 97.9%; SD= 4.7) groups, $t(30) = 1.38$, $p = .18$. Study phase response times were at 1231 ms (SD = 256) in the Misinformed-New group, and 1286 ms (SD = 241) in the Misinformed-Old group, and did not significantly differ between groups, $t(30) = .63$, $p = .53$.

4.3.2.2 RTs and priming

Analyses were performed on mean of median RTs. RTs were recorded for items for which participants received correct information (correctly cued old and correctly cued new) and those for which they received incorrect information (incorrectly cued new items in the Misinformed-New group and incorrectly cued old items in the Misinformed-Old group; see Figure 4.3). A total of 335 out of a total 3840 trials (8.72%) were removed due to incorrect identification etc (187 in the Misinformed-Old group, and 148 in the Misinformed-New group).

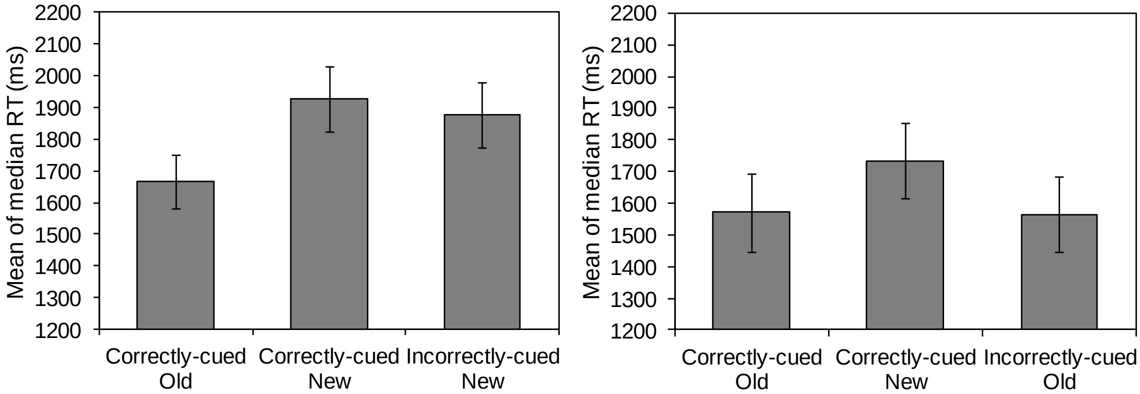

Figure 4.3. Left panel: Identification times for correctly-cued old, correctly-cued new and incorrectly-cued new items in the Misinformed-New group in Experiment 9. Right panel: Identification times for correctly-cued old, correctly-cued new and incorrectly-cued old items in the Misinformed-Old group. Error bars indicate SEM.

One-way repeated measures ANOVAs indicated a significant main effect of item-type in the Misinformed-New group, $F(2, 30) = 29.3$, $p < .001$, $\eta_p^2 = .66$, and the Misinformed-Old group, $F(2, 30) = 5.67$, $p = .01$, $\eta_p^2 = .28$. The assumption of sphericity was not violated, as indicated by Mauchly's statistic. In the Misinformed-New group, RTs for incorrectly-cued new items (new items that were cued 'old') did not significantly differ from those of correctly-cued new items, $t(15) = 0.82$, $p = .43$, and in the Misinformed-Old group, RTs for incorrectly-cued old items (old items that were cued 'new') did not significantly differ from those of correctly-cued old items, $t(15) = 0.28$, $p = .78$. In the Misinformed-New group, correctly-cued old items were identified significantly faster than correctly-cued new items, $t(15) = 7.66$, $p < .001$, $d = 0.69$ (a priming effect), and incorrectly-cued new items, $t(15) = 4.53$, $p < .001$, $d = 0.55$, and in the Misinformed-Old group, correctly-cued new items were identified significantly slower than correctly-cued old items, $t(15) = 2.47$, $p = .03$, $d = 0.34$ (a priming effect), and incorrectly-cued old items, $t(15) = 2.44$, $p = .03$, $d = 0.36$. In other words, identification speed only varied in each group as a function of the actual status of the items (old/new) and not the information provided to participants about the items. Collapsed across true item status, priming (Figure 4.4) did not significantly differ between groups, $t(30) = 1.06$, $p = .30$.

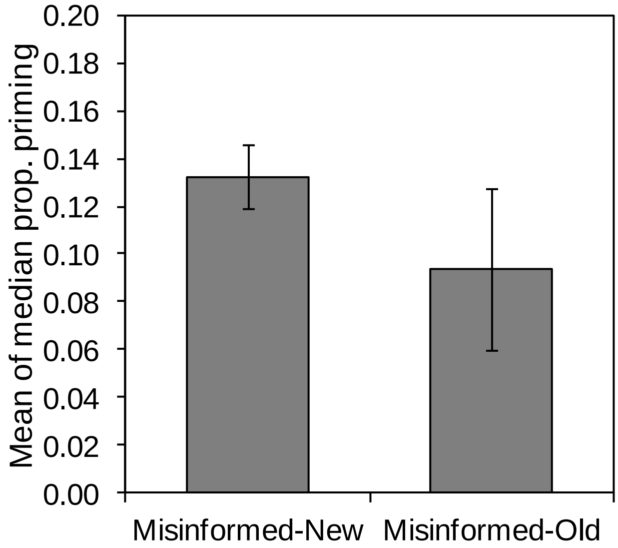

Figure 4.4. Priming (calculated based on true item status) in the Misinformed-New and Misinformed-Old groups in Experiment 9. Error bars indicate SEM.

These results add further weight to the general observation that providing participants with explicit information (correct or incorrect) does not affect the speed of identification of previously studied items in the CID task, nor the amount of priming. A final experiment attempted to shed further light on the proportion effect obtained in Experiment 7, in which presenting a high proportion of old items at test yielded greater priming relative to presenting a low proportion of old trials. Experiment 10 was designed to test the claim that the effect was not driven by greater explicit processing in the High relative to the Low groups.

4.4 Experiment 10

In Experiment 7 the ratio of old to new test trials was varied in order to segregate groups of test aware and unaware participants in the Uninformed condition (in High and Low groups, respectively). However, if the effect of proportion upon priming was due to greater explicit processing in the High groups, this manipulation should have yielded a difference in priming only between the Uninformed High and Uninformed Low conditions, and not between the Informed High and Informed Low conditions (in other words, there would be an interaction between the factors rather than a main effect of proportion). All informed participants were given optimum information to support the successful use of an explicit strategy (they were informed prior to each CID trial whether the next item to be identified was old or new), so witnessing a high or low proportion of old items at test would have provided no additional advantage or detriment towards the use of an explicit strategy. That is, participants in the Informed Low group would have been just as able to use a successful explicit strategy as participants in the Informed High group. It is therefore unlikely that the effect of proportion on priming reflects greater explicit processing in cases when the ratio of old to new items is high relative to when it is low. Although establishing the basis of the proportion effect goes beyond the scope of the present thesis, it is nevertheless important to the general conclusions that this argument is further substantiated.

To achieve this aim, in Experiment 10 the ratio of old to new trials was varied (low versus high) between two groups of participants who also received incorrect information about a subset of trials (similarly to Experiment 9). Participants in the Low group were subjected to twice as many new than old items during the CID task, and participants in the High group witnessed twice as many old than new items. Participants were given an ‘old/new’ prompt before each trial, which was valid on the majority of trials; however the cues provided to participants in the Low group were inaccurate on half of the new item trials (they were cued ‘old’), and the cues provided to participants in the High group were inaccurate on half of the old item trials (they were cued ‘new’).

The rationale of this design is that, although the proportions of old/new test items truly varied between the groups, the cues provided in relation to the items reinstated equality. It was assumed that participants only attempt to recollect items in the CID task on trials cued ‘old’ and not those cued ‘new’, thus participants in the High group were discouraged from using explicit processing on half of the old item trials (i.e., the ones cued ‘new’), even though they witnessed twice as many such trials as did the Low group. If explicit processing affects identification times in the CID task, then one would expect these items to be associated with slower responses than correctly cued old items, and would thus expect the proportion effect to be dissolved. On the other hand, obtaining a proportion effect similar to that observed in Experiment 7 would bolster the claim that the effect is not due to greater explicit processing in the High group. It is, however, noted that the effect of proportion is very small – it only reached significance in Experiment 7 with a very large sample of participants (although it was present numerically in Experiment 4).

4.4.1. Method

4.4.1.1 Participants

There were 16 participants in each of the Low and High groups. All were students from UCL who participated for a small payment. There were 11 males and 21 females with an overall mean age of 22.4 years (*SD* = 2.9).

4.4.1.2 Stimuli and procedure

The same stimuli and object categories were used once more. In this experiment there were 80 study trials and 120 CID trials, and the experiment took around 25 minutes in total to complete. Participants in the Low group witnessed 40 old and 80 new items at test, and participants in the High group witnessed 80 old and 40 new items. In the CID phase, participants were prompted before each trial with the word 'OLD' or 'NEW' as described previously, but both groups received incorrect information on 40 trials. Participants in the Low group were informed that 40 new items were old (incorrectly cued new items), and participants in the High group were informed that 40 old items were new (incorrectly cued old items).

4.4.2 Results and Discussion

4.4.2.1 Study

Categorization accuracy did not significantly differ between the Low (*M* = 96.9%; *SD*= 4.1) and High (*M* = 98.1%; *SD*= 3.4) groups, $t(30) = 0.88$, $p = .39$, and similarly response times did not significantly differ between groups (Low M = 1363 ms, *SD* = 256; High M = 1257 ms, *SD* = 241, $t(30) = 1.15$, $p = .26$.

4.4.2.2 RTs and priming

Analyses were based on mean RTs due to unequal numbers of old and new items at test. Once again the analysis was based on RTs for items for which participants received correct information (correctly cued old and correctly cued new items) and those for which they received incorrect information (incorrectly cued new items in the Low group and incorrectly cued old items in the High group; see Figure 4.5). 297 out of a total 3840 trials (7.73%) were removed due to incorrect identification etc (134 in the Low group, and 163 in the High group).

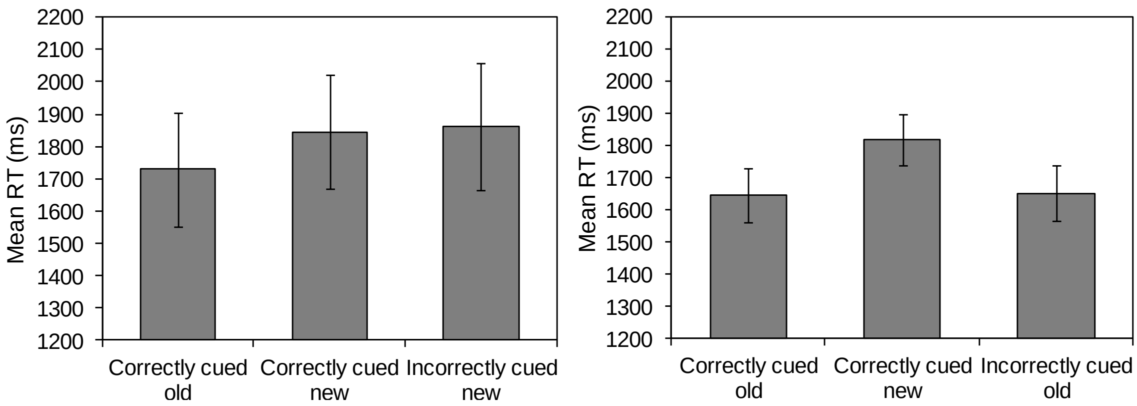

Figure 4.5. Left panel: Identification times for correctly-cued old, correctly-cued new and incorrectly-cued new items in the Low group in Experiment 10. Right panel: Identification times for correctly-cued old, correctly-cued new, and incorrectly-cued old items in the High group. Error bars indicate SEM.

There was a significant main effect of item type in the Low group, $F(2, 30) = 8.06$, $p = .002$, $\eta_p^2 = .35$, and the High group, $F(2, 30) = 14.98$, $p < .001$, $\eta_p^2 = .50$. Once again the assumption of sphericity was not violated. In the Low group, RTs for incorrectly-cued new items did not significantly differ from those of correctly-cued new items, $t(15) = 0.66$, $p = .52$, and in the High group, RTs for incorrectly-cued old items did not significantly differ from those of correctly-cued old items, $t(15) = 0.37$, $p = .72$. In the Low group, correctly-cued old items were identified significantly faster than correctly-cued new items, $t(15) = 3.54$, $p = .003$, $d = 0.16$ (a priming effect), and incorrectly-cued new items, $t(15) = 2.93$, $p = .01$, $d = 0.18$, and in the High group, correctly-cued new items were identified significantly slower than correctly-cued old items, $t(15) = 4.19$, $p = .001$, $d = 0.52$ (a priming effect), and incorrectly-cued old items, $t(15) = 3.91$, $p = .001$, $d = 0.49$. Thus, once again, identification latencies only varied in each group as a function of the actual status of the items (old/new) and not as a function of the information provided to participants about the items.

Collapsed across true item status, priming (Figure 4.6) did not significantly differ between the Low and High groups, $t(30) = 1.13$, $p = .27$, although there was a clear numerical trend in the predicted direction. This experiment provides direct evidence that the effect on priming of varying the proportion of old items at test is not due to heightened explicit processing in cases where the ratio of old to new items is high.

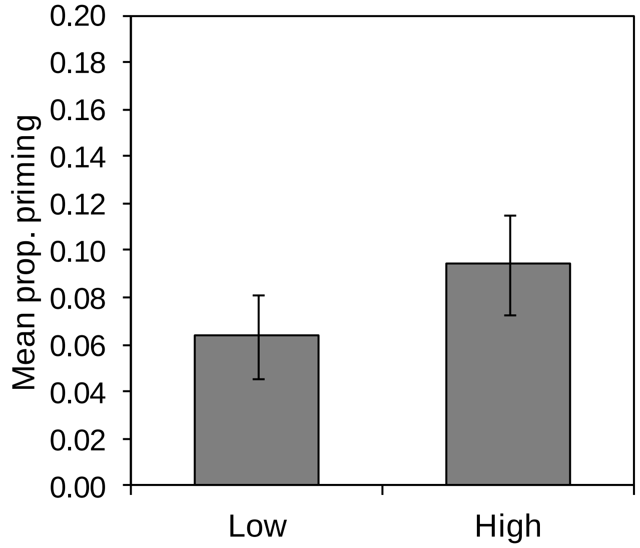

Figure 4.6. Priming (calculated based on the true item status) in the Low and High groups in Experiment 10. Error bars indicate SEM.

4.5 Chapter Summary

The experiments presented in this chapter provide evidence that explicit processing during the CID task does not affect the magnitude of priming obtained. This was tested by (1) comparing priming in participants who were strongly encouraged to use an explicit processing strategy to that in participants who performed the CID task under standard implicit instructions, and (2) comparing identification latencies in the CID task for items for which participants received correct cueing information (e.g., ‘old’ before an old trial), to items for which they received incorrect information (e.g., ‘new’ before an old trial). The awareness questionnaire was administered in Experiments 7 and 8, allowing us to extract participants who spontaneously became test aware in uninformed or low awareness conditions (in Experiments 9 and 10 all participants were test informed). In no instance did priming differ between participants who received correct explicit information about the items ahead of each test trial and those in uninformed conditions who remained test unaware for the duration of the experiment.

Moreover, identification latencies in the CID task only varied as a function of the actual status of the items and not the cues provided, whether correct or incorrect. Based on these observations, it is concluded that the age difference in priming reported in Chapter 2 does not reflect differences in explicit processing between groups of young and older adults. Even if young adults had engaged in explicit processing while older adults did not, the evidence suggests that this would not have altered the magnitude of priming observed. The age difference in priming therefore represents a genuine decline in implicit memory function with age. This conclusion has fundamental implications for the multiple-systems view of memory, as witnessing an age-related reduction on indices of both explicit and implicit memory calls into question the necessity of drawing a distinction between the memory systems that are thought to support them.

Chapter 5: General Discussion

This thesis examined the question of whether implicit memory (as measured by priming) is preserved in normal ageing despite reduced explicit (recognition) memory. Many researchers have argued that performance on indirect or implicit memory tests is age-invariant, in contrast to performance on direct or explicit tests which is widely acknowledged to decline with age. As outlined in the Introduction, this particular dissociation has been heavily cited in the literature as evidence for the existence of separate and independent systems driving explicit and implicit memory. However, a significant age effect on measures of priming and recognition using the CID-R task was obtained here, which questions the necessity of making a distinction between memory systems. From a second stream of experiments we provide a considerable body of evidence that the priming measure employed here is not susceptible to explicit contamination, strengthening the conclusion that the age effect in priming is genuinely due to a decline in implicit memory phenomena with age rather than the use of explicit processing which boosted priming in young individuals. In the following subsections I summarise the main findings obtained in the thesis and discuss their implications for current theories of cognitive ageing and the organisation of memory.

5.1 Explicit and implicit memory in normal ageing

While it is generally accepted that explicit memory declines with age, studies comparing performance on implicit tasks in young and older adults are beset with contradictory findings (reviewed in Fleischman, 2007; Fleischman & Gabrieli, 1998; Mitchell, 1989). As discussed in the Introduction, this is likely to be due to a range of methodological differences between studies, and differences in samples of young and older participants. I outlined a range of considerations that I deemed important to put in place in order to make theoretical advancement in understanding whether an implicit form of memory is preserved in normal ageing, including recruiting otherwise comparable samples of young and older participants, and using a task which is more likely to yield comparable samples of explicit and implicit memory. In Experiments 1 and 2 of the present thesis each test item elicited a recognition and priming judgement in a single trial (CID-R task), and it was found that recognition memory was significantly lower in older relative to young adults, while priming was numerically reduced. These observations were replicated in Experiment 3 when the priming (CID) and recognition tasks were presented separately to reduce test awareness and minimise the possibility that the small age difference in priming was due to explicit contamination. I argued that the age-related reduction in priming reflects a true decline in performance on this indirect task and that low measure reliability meant that the effect did not reach significance in the individual experiments. I demonstrated empirically that the priming task was statistically less reliable than recognition, and the age difference in priming reached significance in a combined analysis of the data which increased statistical power.

The observation that priming is affected by age is compatible with a subset of other studies (e.g., Abbenhuis et al., 1990; Chiarello & Hoyer, 1988; Hultsch et al., 1991; Russo & Parkin, 1993), and the meta-analysis by La Voie and Light (1994). Studies which claim to have detected an effect of age on explicit but not implicit memory have typically depended on a null result in priming, and because age effects in priming are often very small, it is likely that in many cases they have simply gone undetected or been masked by extraneous factors. Others have cautioned against presenting null effects in priming as evidence that an implicit form of memory is spared under certain conditions (e.g., Buchner & Wippich, 2000; Dunn, 2003; Ostergaard & Jernigan, 1993). It has also been argued that priming may be more or less affected by age depending on the particular cognitive processes engaged in the indirect task. Conceptual processing is thought to be affected by age to a greater extent that perceptual processing (Fleischman & Gabrieli, 1998; Geraci & Hamilton, 2009; Roediger & Blaxton, 1987), and production processes to a greater extent than identification (e.g., Rybash, 1996), yet this thesis reports evidence that priming is reduced by age on a perceptual identification task. Another hypothesis for the differential pattern of age effects in priming is that the extent to which older adults exhibit deficits on indirect tasks depends on whether the task relies on creating and retrieving associations between items, which requires the integrity of the medial temporal lobe (Chun, 2005; Naveh-Benjamin, 2000). More work is needed to elucidate the specific conditions (if any) under which priming is spared in old age, but I stress that future studies looking at age effects on performance on indirect tasks should be rigorously controlled.

In some of the experiments young and older adults differed on objective measures of visual acuity, processing speed, and vocabulary, but it is worth noting that it is unlikely that these differences contributed towards the age difference on the priming measure. None of these variables were reliably correlated with priming. Moreover, differences in processing speed were accounted for with the use of a proportional priming measure, and vocabulary scores were higher in older relative to young adults.

Consistent age differences on the recognition task were observed, similarly to a host of prior studies (e.g., Burke & Light 1981; Howe; 1988; Hultsch & Dixon 1990; Jelicic et al., 1996). Although recognition is a widely used measure of explicit memory, age differences are not always found on this type of task (see Schugens et al., 1997; Moscovitch & Winocur, & McLachlin, 1986; Naveh-Benjamin & Craik, 1995). As outlined in the Introduction, it is widely agreed that successful recognition can be facilitated by familiarity-based processing and/or recollection. It is also widely believed that older adults rely more on familiarity processes to support memory, whereas young individuals are better at recollecting previously studied information (e.g., Light et al., 2000; DeCarli et al., 2010), so the lack of an age difference that is sometimes reported on recognition tasks is said to reflect spared familiarity-based processing in older individuals. By the same token, it may be argued that the present observations of age differences in recognition memory are reflective of differences between groups in the ability to recollect previously studied items. The findings also suggest that recognition tasks are a suitable tool for comparisons of explicit memory across different age groups.

In sum, consistent with prior studies, the present experiments uncovered reductions in explicit memory with age that are similar to those seen in amnesia, albeit much less drastic. However, there is also evidence that cognitive ageing affects performance on indirect memory tasks when appropriate control measures are put in place and adequate statistical power is achieved. This observation is important for current theories of cognitive ageing, as they point to a general decline in memory with age, rather than a differential pattern of spared and impaired cognition. Although I argue against the idea that an implicit form of memory which is separate from explicit memory is preserved in normal ageing, more work is needed to examine whether memory in older individuals is dominated by familiarity-based processing, and whether the deficits in explicit memory with age reflect a specific decline in older individuals in the ability to recollect information from memory. I hope that the findings presented here will be useful for furthering our understanding of the changes in memory that occur with age, and in the development of memory rehabilitation techniques. Research into memory maintenance with age deserves further investment in the future, and is especially important in a society in which individuals are living longer.

5.2 Explicit contamination in perceptual identification tasks

Age effects in priming have often been attributed to explicit contamination. As outlined in the Introduction, if participants become test aware during an indirect memory task, they may, in contrast to the task instructions, opt to use an explicit processing strategy. Explicit processing during an implicit task could contribute towards an age difference on a priming measure because young and older adults are likely to differ in their ability to use such a strategy (since young individuals usually outperform older adults on explicit tasks). Russo and Parkin (1993) found an age difference in priming on a fragmented picture completion task, but showed that the effect disappeared when explicit memory was equated between groups (young participants performed a dual study task). Moreover, Geraci and Barnhardt (2010) found greater levels of test awareness and priming in young relative to older adults on word-stem completion and category production tasks, and a greater relationship between the two, which was taken as evidence that awareness mediates age effects in priming. Furthermore, Park and Shaw (1992) demonstrated a small, nonsignificant age difference in priming on a word-stem completion task, but means were identical for young and older participants who were test unaware (.08). In contrast, in Experiment 3 of the present thesis, the numerical age difference in priming persisted when the data from aware participants were removed (.13 and .08 for young and older adults, respectively).

The effects of test awareness and explicit processing on priming in the CID-R paradigm were further examined in Chapters 3 and 4. Experiments 4, 5, and 6 demonstrated that priming in this task is generally unaffected by manipulations of test awareness. Task type (CID versus CID-R) was varied under the assumption that the CID-R task would induce greater test awareness relative to the CID task in which there is no concurrent explicit judgement. Participants are also test-informed in the CID-R task, in contrast to the standard implicit instructions involved in the CID task. The proportion of old trials at test (low versus high) was also varied, which was found to be successful at segregating test aware and unaware groups of participants for comparison. Things were taken further in Experiments 7, 8, 9, and 10, and attempted to create optimal conditions for the use of an explicit strategy in the CID task. Priming in participants who were informed of the old/new status of each test item immediately before it was presented did not differ to that in uninformed participants (Experiments 7 and 8), and in Experiments 9 and 10 identification times in the CID task only varied with respect to the actual status of the items (old/new) and not the cues provided for the items, whether correct or incorrect. Overall, the findings presented here provide strong evidence that the CID task is immune to explicit contamination.

Several other studies have examined the effects of test awareness and explicit processing on priming in young individuals, but results have been mixed. Bowers and Schacter (1990) found no difference in priming between informed and uninformed participants on a word-stem completion task, and no interaction with a levels-of-processing manipulation, although priming was greater in uninformed participants who spontaneously became test aware relative to those who did not (Experiment 1). In contrast, Mace (2003) reported enhanced priming in informed relative to uninformed participants for items studied under semantic but not nonsemantic conditions. Similarly to the present Experiments 4 and 5, Brown et al. (1996) found that priming did not differ when identification trials were immediately followed by recognition judgements relative to when the priming task was presented alone (see also Stark & McClelland, 2000). Moreover, Brown et al. (1991) found no difference in priming when old and new test trials were presented in separate blocks (and participants were informed which block contained which type of item) versus interleaved. As with the present informed versus uninformed manipulation in Experiments 7 and 8, this would have provided good conditions for the use of explicit processing.

Some may argue that explicit processing may have hindered the performance of older individuals in the CID task, resulting in lower priming in this group. This is unlikely given the evidence that the CID task is unaffected by both optimal and adverse explicit processing: performance was not improved when correct explicit information was provided to support performance (Experiments 7 and 8), and it was not worsened when explicit processing was disadvantageous because incorrect cues were provided (Experiments 9 and 10). Thus, although some priming tasks may be more susceptible to the effects of explicit contamination, it is suggested that this is not an issue in the CID-R paradigm. This is very important given the usefulness of this task in assessing the relationship between recognition and priming – researchers can be fairly confident that the test awareness associated with the task has no effect on the priming outcome. Even if test awareness induces the use of explicit processing during the identification (CID) task, this does not affect response latencies. It is perhaps more effortful to support speeded object identifications with a search of explicit memory, and it has also been argued that identification of items precedes recollection (see MacLeod, 2008). As such, explicit processing is likely to be a bigger issue on tasks such as word-stem completion, where the use of an explicit strategy has the clear potential to improve performance. Numerous prior studies have employed this task, but because the present findings suggest that many participants spontaneously become test aware during implicit tasks, it is recommended that test awareness and explicit processing be rigorously monitored in future studies using this task.

The current study revealed an effect of varying the number of old trials in the priming task in Experiment 7. A high proportion of old trials resulted in stronger priming relative to a low proportion. The effect, which appears to be genuine but very small, was only significant in this single experiment with a large sample of participants. A numerical effect in the same direction was present in Experiments 4 and 10, but was reversed in Experiment 6. A handful of other studies have also varied the ratio of old to new test items: Jacoby (1983) reported enhanced priming on a word naming task in informed participants who witnessed 90% old trials at test relative to uninformed participants who were exposed to 10% old trials, but it is impossible to know whether the enhancement of priming was due to the instructions or the different ratios of old and new items.

As noted in Chapter 4, it is unlikely that the effect of proportion is due to greater explicit processing in groups exposed to a high ratio of old to new items at test (by inducing greater test awareness in relation to participants exposed to a low proportion of old items). The effect was also present in groups of informed participants who already received optimal information about test items in order to support a successful explicit strategy – that is, they received a cue prior to each CID trial informing them of whether the item to be identified was old or new. If the effect is due to greater explicit processing in groups subjected to a high ratio of old to new items, then one would have only expected to find an effect of proportion in the uninformed conditions. Experiment 10 provided further evidence that the proportion effect is not due to explicit contamination – the effect was evident (numerically) when participants who witnessed a high proportion of old trials were strongly discouraged from engaging in explicit processing on half of the old-item trials they witnessed (they were incorrectly informed that these trials depicted new items). Overall, the influence on priming of varying the number of old trials at test is not well understood and merits further investigation. One hypothesis to explore is that a disproportionate number of old and new trials creates a motivational imbalance which affects the speed of responding. In the majority of the experiments reported here, identification times were faster overall in the high conditions, suggesting that participants' general ability to identify objects was boosted under such circumstances.

In sum, this thesis presents a range of evidence that priming in the CID task is immune to explicit contamination. This is beneficial for the interpretation of the age difference in priming reported in this thesis: it suggests that the effect is genuinely due to a decline in implicit memory function with age rather than to explicit contamination in the priming task which boosted priming scores in young individuals. More work is needed to establish the extent to which explicit processing affects priming on other commonly used indirect memory tests, and it is also necessary to directly compare the performance of young and older adults under manipulations of explicit orientation. Although it was not a focus in the present thesis, the issue of 'implicit contamination' is also interesting – that is, the extent to which fluent processing due to prior exposure to test stimuli affects performance on explicit tasks. Generally, it is believed that the contribution of fluency from priming to subsequent recognition memory in the CID-R paradigm is very minor (Conroy et al., 2005; see also Sheldon & Moscovitch, 2010), but future research could explore this issue in more depth and examine potential interactions with age effects in explicit memory.

5.3 Critical evaluation

It should be noted that the statistical power of the individual aging experiments in this thesis was low (ranging from .17 to .26). Power was increased to a moderately acceptable level in the pooled data-analysis (.52). In an ideal situation, one or two larger experiments would have demonstrated the critical observation of a significant age difference in priming, but this is a difficult aim to achieve given that the effect is very small – many more participants would have had to be tested. Underpowered studies have been an issue in this field for many years (an excellent discussion is provided by LaVoie & Light, 1994), and the experiments reported in this thesis confirm that this masks a genuine reduction in priming with age. Although the present empirical evidence for the age difference in priming is clear, one should note just how small the effect is. I hasten to add, however, that this may be one of the rare cases in which a small effect is genuinely very important: obtaining an age difference in priming, no matter how small, questions the claim that it is spared in normal aging.

One must also take caution in the fact that several key findings reported here rest on null result (the explicit contamination experiments reported in Chapters 3 and 4), something which was criticised in the Introduction. While it is emphasised that no firm conclusions should be drawn on the basis of a non-significant difference between comparisons of interest, the evidence from the present explicit contamination chapters remains on a relatively stable footing. There was no hint of a difference between the critical comparisons (Informed versus Uninformed groups) even when a large sample was used, such as in Experiment 7. Moreover, many critical comparisons yielded non-significant differences wherein the mean trends did not present a concern over a potential Type II error (that is, the trend was not in a direction that could be taken as a clue that explicit processing affects priming).

Another point that deserves consideration is the low reliability estimates for the priming task. Implicit tasks are generally acknowledged to have lower reliability than explicit tests (this is predicted by the single-system model and forms the basis of the argument as to why effects are more difficult to detect using implicit tasks), but one may wonder how the CID-R task is capable of successfully measuring priming when many of the split-half correlations were very low or even negative. How is it that this task is capable of capturing a meaningful and robust construct? If, as assumed by the single-system model, priming consists of a fixed, memorial, component as well as non-memorial noise, then the pattern of data is not so surprising. For instance, the fixed component could be fairly similar across trials and participants, yielding a strong aggregate priming effect. If at the same time the noise component is uncorrelated across trials and participants, then reliability measured across odd and even test trials will be low or even zero. It will be an important question for future research to analyse reliability data in other types of priming or implicit memory measures (see Buchner & Brandt, 2003, for one such analysis of data similar to those obtained here).

5.4 Conclusions and implications for multiple memory systems

The present findings challenge the notion that performance on implicit memory tests is resistant to the age-related decline that affects performance on explicit tests. This, in turn, presents a clear challenge to the multiple-systems view of memory, which states that there are separate and functionally independent explicit and implicit memory systems which support these forms of memory (e.g., Gabrieli, 1998, 1999; Schacter, 1987; Schacter & Tulving, 1994; Squire, 1994, 2004, 2009; Tulving & Schacter, 1990). This view predicts no effect of age on indices of implicit memory, and suggests that the deficits occurring with age on explicit tests are attributable to the selective compromise of the explicit (or declarative) memory system, while the implicit (or nondeclarative) system is unaffected. In contrast, the findings support the view that a distinction should not be drawn between explicit and implicit memory phenomena, and that the two are driven by a unitary system which is subject to age-related decline (see Berry et al., 2006; Berry et al., 2008a, 2008b; Buchner & Wippich, 2000; Dunn, 2003; Nosofsky et al., 2012).

An abundance of evidence has accumulated over the years which many researchers believe points to separate memory systems (reviewed in Roediger & McDermott, 1993), yet, as outlined in the Introduction, much of this can be accommodated by the single-system view. Single dissociations, such as when an experimental manipulation affects performance on an explicit test but produces a null effect on an implicit test, can be accounted for by the generally lower power and reliability in implicit tests. Indeed, single-system computational models (such as the model by Berry and colleagues) can predict such observations merely by assuming that performance on the indirect task is noisier than that on the direct task. Other compelling evidence for multiple systems is priming in the absence of explicit memory (e.g., Butler & Klein, 2009; Hamann & Squire, 1997a, 1997b; Kunst-Wilson & Zajonc, 1980; Merikle & Reingold, 1991; Stark & McClelland, 2000; Vuilleumier et al., 2005), and intact priming in individuals with amnesia who demonstrate very weak or chance levels of recognition (e.g., Conroy et al., 2005; Graf et al., 1984; Hamman & Squire, 1997a, 1997b; Jacoby & Witherspoon, 1982; Stark & Squire, 2000; Warrington &

Weiskrantz, 1970, 1974). However, as outlined in the Introduction, many of these observations have proven difficult to replicate (Berry et al. 2010; Moscovitch & Bentin, 1993), and there are also published instances in which amnesic patients do not show spared implicit memory (Chun & Phelps, 1999; Squire, Shimamura, & Graf, 1987). Others have shown that recognition and priming are independent at the item level – that is, demonstrating robust priming for items that are not able to be consciously recognised. For example, Mitchell et al. (1990) reported equivalent priming for all old items regardless of whether or not they were explicitly retrieved from memory, but in the item analyses reported in this thesis, identification latencies were consistently faster for items that were explicitly remembered (hits) relative to those that were forgotten (misses).

Of course, advocates of the multiple-system theory may rightly argue that the present findings do not necessarily provide ‘proof’ that different expressions of human memory are driven by a single system. One could argue that observing similar effects of a factor (such as age) on tests of explicit and implicit memory simply demonstrates parallel effects of this factor on separate memory systems. That is, there could be two independent memory systems driving explicit and implicit memory, but both could be affected by age in the same way. I do not refute this argument; but add that supporters of this view must accept that the alternative explanation, that the two are driven by the same underlying system, is equally as plausible. Moreover, the finer item analyses described above provide compelling support for the single-system view, and do not readily support the multiple-systems theory. Given these points, this thesis presents a challenge to the widely held and more traditional multiple-systems view. In order to make further progress in this debate, one must turn to examining the robustness of reports of reversed dissociations, which constitute more persuasive evidence for multiple systems. Voss and Gonsalves (2010) recently provided intriguing evidence that manipulating the duration with which items are studied (brief versus long) differentially affects subsequent recognition and priming. Long study resulted in better recognition of items relative to brief study, while priming benefited more from brief relative to long study. This observation is in need of further examination, and it will be particularly interesting to establish whether it can be accommodated by a single-system model.

A great deal of progress has been made in recent years in understanding the relationship between explicit and implicit forms of memory, and the present work makes a substantial new contribution. Although there is not yet a conclusive answer to the question of whether these memory phenomena are driven by a single or multiple memory systems, the combination of contemporary behavioural methods, computational modelling, and functional imaging is likely to offer further theoretical insights in the near future. I believe there should be a continued interest in exploring questions about the nature of explicit and implicit memory using special populations including healthy older individuals and individuals with amnesia, who are known to exhibit deficits in explicit memory function and thus provide a unique opportunity to test specific priming predictions.

In summary, the evidence presented in this thesis leads us to conclude that an implicit form of memory is not preserved in healthy ageing, and that normal age-related cognitive decline leads to the compromise of a unitary memory system which supports both explicit and implicit expressions of memory. There is no doubt that many experimental factors produce effects on indirect memory measures that are smaller than those on direct measures, but it is apparent that this can be accounted for by the lower power and reliability of the former, and does not reflect the distinct cognitive operations of independent memory systems. I hope that increased theoretical transparency of the organisation of human memory will promote our understanding and rehabilitation of memory problems caused by ageing and neurodegenerative disease.

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Appendix

Table A1. Proportion hits, misses, false alarms (FA), and correct rejections (CR) for the recognition task in Experiment 1.

	Young (Immediate Test)	Older (Immediate Test)	Young (Delayed Test)	Older (Delayed Test)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Hits	.72 (.15)	.59 (.17)	.63 (.20)	.51 (.21)
Misses	.28 (.12)	.41 (.18)	.37 (.18)	.49 (.13)
FA	.18 (.11)	.21 (.12)	.19 (.13)	.21 (.13)
CR	.82 (.18)	.79 (.15)	.81 (.17)	.79 (.17)

Note: Hits: old items correctly judged old; Misses: old items incorrectly judged new; FA: new items incorrectly judged old; CR: new items correctly judged old. There were 30 old trials and 30 new trials in each test, and the proportions were calculated for each participant by dividing the number of responses in each category by the total number of trials, e.g. 21(hits)/30(total old trails).

Table A2. Proportion hits, misses, false alarms (FA), and correct rejections (CR) for the recognition task in Experiment 2.

	Young	Older
	M (SD)	*M (SD)*
Hits (immediate items)	.74 (.16)	.62 (.16)
Hits (delayed items)	.67 (.17)	.56 (.18)
Misses (immediate items)	.26 (.16)	.38 (.17)
Misses (delayed items)	.33 (.17)	.44 (.19)
FA	.26 (.17)	.24 (.13)
CR	.74 (.17)	.76 (.14)

Note: There were 60 old trials (30 immediate and 30 delayed) and 60 new trials in total.

Table A3. Proportion hits, misses, false alarms (FA), and correct rejections (CR) for the recognition task in Experiment 3.

	Young	Older
	M (SD)	*M (SD)*
Hits	.61 (.14)	.40 (.19)
Misses	.39 (.16)	.60 (.17)
FA	.21 (.22)	.22 (.13)
CR	.79 (.18)	.78 (.17)

Note: In this experiment there was a single recognition phase with 30 old and 30 new items trials.

Table A4. Proportion hits, misses, false alarms (FA), and correct rejections (CR) for the recognition task in the two CID-R conditions (Low and High) in Experiment 4.

	CID-R Low	CID-R High
	M (SD)	*M (SD)*
Hits	.82 (.13)	.69 (.13)
Misses	.18 (.15)	.31 (.19)
FA	.34 (.23)	.48 (.36)
CR	.66 (.18)	.52 (.22)

Note: There were 120 old and 30 new item trials in the recognition phase in the CID-R High condition, and 30 old and 120 new item trials in the CID-R Low condition.

Table A5. Proportion hits, misses, false alarms (FA), and correct rejections (CR) for the recognition task in the two CID-R conditions (first and second) in Experiment 5.

	CID-R task first	CID-R task second
	M (SD)	*M (SD)*
Hits	.73 (.16)	.62 (.14)
Misses	.27 (.17)	.38 (.15)
FA	.17 (.11)	.21 (.14)
CR	.83 (.19)	.79 (.11)

Note: There were 40 old and 40 new item trials in the recognition phase in both conditions.