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Memory, Language and Ageing

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Abstract
This overview provides both theoretical and empirical reasons for emphasizing practice and familiar skills as a practical strategy for enhancing cognitive functioning in old age. Our review of empirical research on age-related changes in memory and language reveals a consistent pattern of spared and impaired abilities in normal old age. Relatively preserved in old age is memory performance involving highly practiced skills and familiar information, including factual, semantic and autobiographical information. Relatively impaired in old age is memory performance that requires the formation of new connections, for example, recall of recent autobiographical experiences, new facts, or the source of newly acquired facts. This pattern of impaired new learning versus preserved old learning cuts across distinctions between semantic memory, episodic memory, explicit memory, and perhaps also implicit memory. However, familiar verbal information is not completely preserved when accessed on the output side rather than the input side: Aspects of language production, namely word finding and spelling, exhibit significant age-related declines. This emerging pattern of preserved and impaired abilities presents a fundamental challenge for theories of cognitive ageing, which must explain why some aspects of language and memory are more vulnerable to effects of ageing than others. Information-universal theories, involving mechnisms such as general slowing that are independent of the type or structure of the information being processed, require additional mechanisms to account for this pattern of cognitive aging. Information-specific theories, where the type or structure of the postulated memory units can influence the effects of cognitive ageing, are able to account for this emerging pattern, but in some cases require further development to account for comprehensive cognitive changes such as general slowing.

Memory, Language and Ageing

The dramatic increase during the 20th century in the number of people reaching old age has heightened interest in normal cognitive ageing as a research topic. Although many prominent people remained highly creative or intellectually productive in old age, for example, Frank Lloyd Wright, Marianne Moore, George Bernard Shaw, Claude Monet, Michaelangelo (Lehman 1953; Dennis 1968), these conspicuous cases may represent exceptional or optimal instances of cognitive ageing that do not apply to the average individual. Understanding what cognitive changes normally occur in old age has become critical for determining how normal, exceptional, and pathological cognitive ageing differ, and for delineating the intellectual potential of older adults in our society, and the conditions that enhance it.

Responding to this challenge, research on cognition and ageing has developed rapidly over the past several decades, going beyond its early focus on psychometric intelligence test data to encompass new experimental paradigms and theoretical frameworks from cognitive psychology and the neurosciences. In the past, a rich harvest of empirical findings has overshadowed development of theories for explaining the patterns of cognitive change in old age, but the present paper will discuss recent progress in identifying psychological mechanisms that underlie cognitive ageing. This theoretically oriented work promises specific insights into cognitive resilience and decline in old age, as well as more general insights into the organization of human cognition.

Our main focus is memory and language, domains that are prominent in ageing research and central to understanding human cognition. We start with an overview of empirical research on age-related changes in memory and language, reviewing findings that reveal the patterns of spared and impaired abilities in normal old age. Our goal is to highlight the theoretical and practical implications of these general patterns, rather than to exhaustively review the available data. Because theories must explain both the decline and preservation of different mental abilities with age, we discuss the implications of these patterns of spared and impaired abilities for theories of normal ageing, We conclude with some practical considerations suggested by these patterns or regularities in age-related cognitive changes.

Memory and Ageing

Over the past several decades, researchers have focused on how performance varies for different types of information in memory and for different procedures for testing memory. We examine two such distinctions here, between episodic versus semantic information in memory, and between explicit versus implicit procedures for testing memory. As we will show, these distinctions are relevant to the magnitude of age-related declines in memory.

Episodic Memory

Episodic memory refers to the ability to remember specific events situated in time and place, for example, where we put our keys yesterday or the text of a phone message we just listened to. Older adults exhibit major declines in episodic memory, performing more poorly on laboratory tests that involve episodic recall or recognition of virtually any stimuli, for example, single words or prose passages, spatial locations, pictures, faces, and activities (for reviews see Burke & Light 1981; Light 1991; Craik & Jennings 1992; Smith 1996). These age declines in episodic memory are not because older adults are less motivated to remember unfamiliar or unimportant stimuli used in laboratory tasks because age differences remain in tests of memory for more naturalistic stimuli, e.g., groceries on a shelf (Read 1987), hands in bridge (Charness 1979), board positions in chess (Charness 1981), instructions on bottles of prescription medicine (Morrell et al. 1990), people's names (Cohen & Faulkner 1986; James 1997), and golf shots (Backman & Molander 1986). Age-related declines in episodic memory performance are inversely related to years of education, but nevertheless they usually remain when education is controlled statistically (e.g., Nyberg et al. 1996), or when young and older adults with comparable education or current status as students are tested (e.g., Parks et al. 1986).

The size of the age-linked decline in episodic memory performance depends on the nature of the test. In general, making the test more difficult, for example, by presenting unfamiliar material, by using faster rates of presentation, or by increasing how much material must be recalled, will increase the size of the age differences. The two lower functions in figure 1 illustrate this pattern with data from a study of 1,000 Swedish participants, with 100 adults in each of 10 age groups (Nyberg et al. 1996). The solid and dotted lines represent recall of simple sentences about actions (e.g., Roll the ball) expressed as a percent of the maximum score obtained by any age group, which was the youngest age group for these two tests. For the action memory test, participants heard and enacted the sentences and then recalled them, and for the sentence memory test they heard the sentences and then recalled them. Enacting the sentences improved absolute recall scores so that the action memory test yielded higher scores than the sentence memory test. Performance declined systematically and significantly with ageing for both tests with a larger decline on sentence memory. The third, dashed line in figure 1 represents performance on general knowledge questions which tapped information acquired and used over the life span, rather than recently encountered information. As can be seen in figure 1, general knowledge, unlike episodic memory, showed relatively little age decline with the highest score achieved at age 45. Moreover, the slight decline with age in general knowledge performance in figure 1 is attributable to background differences that were confounded with age in Nyberg et al. (1996). For example, the older participants had lower education levels than the younger participants. When such background characteristics were equated across groups, the age-linked decline disappeared for the general knowledge test, but not for the other, episodic memory tests.

Insert figure 1 here

Some have interpreted such data as evidence for a separate episodic memory system that is especially vulnerable to ageing (e.g., Mitchell 1989). Episodic memory tests, however, are invariably confounded with a more general process known as new connection formation, an aspect of memory that is known to decline in old age (see, e.g., MacKay & Burke 1990). Several types of evidence suggest that new connection formation is the fundamental process underlying declines not just in episodic memory, but in recall of other information as well.

First, the age-linked decline in episodic memory applies primarily to new or recent events experienced in old age, and not to recall of events experienced in the more distant past at a younger age. Memory for events typically declines as time passes since the event, and the rate of forgetting of events in the distant past is very similar for young and older adults. This has been shown for recall of autobiographical memories over the previous 20 years (Rubin et al. 1986) and for recognition of TV shows that aired only one season from 6 to 15 years previously (Squire 1989). When asked, however, to give the first autobiographical memory that came to mind when a cue word was presented, younger adults (age 36-40 years) recalled more autobiographical memories from the last few years of their lives than did older adults (age 56-60 years) who in turn recalled relatively more from their youth. This may occur because older adults' ability to encode new memories was compromised as they aged, resulting in fewer memories from the last few years (Jansari & Parkin 1996). Similarly, Squire (1989) reported an age decrement in recognition of the TV shows aired in the last 5 years but no age differences for shows from the 10 years prior to that.

The second reason for viewing new connection formation as the fundamental process underlying age-linked declines in episodic memory is the essential role of new connection formation in acquiring new episodic memories: New connections must be formed between the to-be-remembered-items, for example words, and the temporal or spatial context in which they appeared. Older adults are less able than young adults to remember the context for specific events, for example, whether they read a word or generated it themselves from a cue (Rabinowitz 1989), whether a word was presented in the visual or auditory modality (Lehman & Mellinger 1984) or whether a word was thought or actually spoken (Hashtroudi et al. 1989; see Spencer & Raz 1995 for a review). Older adults also make more errors than young adults in specifying the source of events: For example, older adults are more likely to erroneously remember that they had seen a sequence of actions performed when they had in fact imagined seeing them performed (Cohen & Faulkner 1989; see Johnson et al. 1993 for a review). This type of memory error has implications for the accuracy of eyewitness reports. After older adults read an inaccurate description of a crime that they had witnessed in a film, they were more likely than young adults to attribute the inaccurate information to the film than to what they had read (Cohen & Faulkner 1989).

Age-linked reduction in episodic memories seems to reflect a decline in new connection formation abilities, with relative sparing of episodic memory in old age when new connections are not required. Moreover, the deficit in forming new connections and the sparing of existing memory representations is a pattern that holds for other types of memories, as we discuss next.

Explicit Versus Implicit Memory

The distinction between explicit versus implicit tests of memory has received considerable attention over the past fifteen years. Explicit tests involve deliberate, conscious recall of a specific prior experience or recognition of whether or not a specific experience occurred. An example is the request to explicitly recall words viewed in a previous task (e.g., eagle) that correspond to cues consisting of the catgory (e.g., BIRD) or initial letters (e.g., EA____); older adults perform more poorly than young adults on such tests. Implicit tests examine effects of a prior experience without requiring conscious or explicit recollection of the specific prior event. For example, when asked to produce an exemplar of the category BIRD, or to complete a stem of initial letters with the first word that comes to mind (e.g., EA____), the word eagle comes to mind more easily if it was viewed in an earlier task, even when participants are unaware of the link to the previous task. This beneficial effect of prior experience is called repetition priming and is typically similar in magnitude for young and older adults (e.g., Light & Singh 1987; Light & Albertson 1989). Such nonconscious effects of prior experience seem to be an important component of functioning in everyday life, influencing, for example, the particular ideas or words that come to mind and the effects of prior practice on performance.

In contrast to explicit episodic memory tests, standard implicit tests such as repetition priming do not require the formation of new connections, but instead reflect the strengthening of existing connections during processing in the prior task. The age declines for explicit but not implicit tests may therefore occur because explicit but not implicit tests require the formation of new connections between memory representations. Interestingly, age deficits have been reported when implicit tests require the formation of new connections, as when novel serial patterns are acquired or novel associations between words must be formed (Howard et al. 1986; Spieler & Balota 1996; Howard & Howard in press). Furthermore, it has been suggested that older adults show less benefit than young adults from prior repetition or practice on complex, unfamiliar tasks and at least comparable benefit on simpler, familiar tasks (Welford 1985). However, not all studies have observed this age-linked decline for implicit tests involving new connection formation (see LaVoie & Light 1994) and further research is needed to identify the relevant variables (Howard 1996). If age differences can be demonstrated for implicit tests requiring new connection formation, this would establish age-linked declines in forming new connections as a fundamental process that cuts across both explicit and implicit tests of memory.

Semantic memory

Another distinction that has played an important role in memory theories concerns semantic memory, our vast store of knowledge and skills, including semantic, orthographic and phonological information associated with our language. Semantic memory is relatively unimpaired with ageing whether tested by explicit or implicit means. For example, direct tests of general knowledge (Nyberg et al. 1996) or of vocabulary (Salthouse 1982) consistently show age constancy throughout adulthood, as does knowledge tested implicitly via priming techniques (Burke in press).

A similar pattern emerges from word association tests, one of the oldest tools in psychology for measuring the organization and availability of semantic information. Word association responses for young and older adults matched for verbal IQ and educational level do not differ in relative response frequency, in number of unique responses, or in overlap of responses within their age groups (e.g., Howard 1979; Lovelace & Cooley 1982; Burke & Peters 1986). A similar pattern also emerges from another measure of how semantic information is organized in memory, descriptions of Òscripts.Ó Scripts are the typical sequence of events associated with familiar activities such as going to a wedding. Script descriptions remain constant across age, with no age differences in typicality or variability of responses (Light & Anderson 1983; Hess 1985).

Even for highly practiced skills such as chess (Charness 1981), bridge (Charness 1979), piano performance (Krampe & Ericsson 1996), and transcription typing (Salthouse 1984), the use of knowledge relevant to the skill is age constant, at least among experts. It is important to note, however, that memory for new semantic information shows the usual age-related declines, both in learning new factual information (McIntyre & Craik 1987; Schacter et al. 1994) and in learning new cognitive skills (e.g., Fisk et al. 1995), new job-related skills (Kubeck et al. 1996), and new motor skills (e.g., Welford 1985).

Summary

The general pattern that emerges from studies of memory and ageing is constancy on tests of familiar or pre-existing information, and age deficits primarily on tests that require the formation of new connections in memory. This pattern cuts across distinctions between semantic memory, episodic memory, explicit memory, and perhaps also implicit memory, thereby challenging a multiple memory systems account in which separate memory systems are differentially affected by ageing. As the next sections show, however, the degree to which memory for pre-existing verbal information is spared in older adults depends on whether the information is accessed on the input side, i.e., language comprehension, or on the output side, i.e., language production.

Language and Ageing: The Input Side

The input side of language involves perception of the letters and speech sounds that make up words, and comprehension of the meaning of words and sentences. These input-side processes remain remarkably stable in old age, independent of sensory deficits (see Madden 1988) and declines in the ability to encode new information. Probably the most popular technique for measuring the processing of word meanings and their organization in semantic memory is the semantic priming paradigm. The semantic priming effect refers to the reduction in the time required to identify a target word, say, DOCTOR, when it follows a semantically related word, e.g., NURSE, rather than a semantically unrelated word, e.g., TABLE. Because this task does not directly ask people whether the two words are related in meaning, semantic priming effects have been attributed to automatic activation of meaning during perception, and spread of excitation (priming) to the meaning of related words, making these related words easier to activate. Thus, perception of NURSE stimulates semantically related information, facilitating subsequent perception of DOCTOR. The fact that semantic priming effects are at least as large in older as young adults (Laver & Burke 1993) is evidence for the integrity of this important language comprehension process in old age.

Age constancy is also found for the processes involved in comprehending words in sentences. For example, when young and older adults read sentences that bias a specific properties of a noun, e.g., oranges in The oranges rolled off the uneven table, they are faster to verify the property of oranges relevant to the sentence, e.g., Oranges-Round?, than to verify a property irrelevant to the sentence, e.g., Oranges-Juicy?. However, property-noun verification was faster for Oranges-Juicy? than for Oranges-Round? after reading The oranges quenched the thirst of the hot children (Burke & Harrold 1988). These findings suggest that meanings of a noun that are relevant to its sentence context are selected when computing the meaning of a sentence, and the equivalent facilitation of relevant rather than irrelevant meanings for young and older adults suggests that this semantic selection process remains constant across age during sentence comprehension.

Techniques developed to measure semantic processes on-line as they occur during sentence comprehension (Tyler 1992) lead to a similar conclusion. For example, participants can identify and respond to the target word BOOKS more quickly in a semantically congruent sentence context (e.g., The accountant balanced the BOOKS), than in a less congruent context, e.g., The train went over the BOOKS (Madden 1988), and facilitation from congruent sentence contexts is at least as large for older as for young adults, suggesting age constancy in the on-line interpretation of words as they occur in sentences (see also Cohen & Faulkner 1983; Burke & Yee 1984; Nebes et al. 1986; Stine & Wingfield 1994; Wingfield et al. 1994).

Studies using Òon-lineÓ techniques rule out a major confound inherent in Òoff-lineÓ tasks that measure comprehension processes by examining what people remember about the meaning of sentences or paragraphs presented earlier. Age differences invariably appear in such Òoff-lineÓ tasks (e.g., Hartley 1988; Hartmann & Hasher 1991; Hamm & Hasher 1992), but may have less to do with initial comprehension than with the process of encoding and recall of the comprehended information (see e.g., Burke & Harrold 1988; Stine et al. 1996). For example, results of some off-line studies may reflect the age-linked deficit in forming new connections necessary to link comprehended information to its temporal and spatial context, including the information source. In sum, when encoding of new information is factored out, evidence for age constancy in language comprehension and in the structure and retrievability of general knowledge is both strong and consistent (MacKay & Burke 1990; Light 1991; Kemper 1992b; MacKay & Abrams 1996; Tun & Wingfield 1993; Burke in press).

Language and Ageing: The Output Side

Unlike language comprehension, language production is not immune to effects of ageing: Aspects of spoken and written language production consistently show age-related declines, independent of deficits in the ability to encode new information. In particular, older adults often complain of increased difficulty in producing words that they know (Cohen & Faulkner 1986; Sunderland et al. 1986). This word retrieval problem is not due to deficits in formulating the idea to be expressed, but rather appears to reflect an inability to map a well defined idea or lexical concept onto its phonological or orthographic form. By way of illustration, consider one of the most sensational instances of word retrieval difficulty, the tip of the tongue (TOT) state, in which a person is temporarily unable to produce a word even though they are absolutely certain that they know the word and its meaning. Often a person in the throes of a TOT reports a few phonological features of the word such as its stress pattern and initial letter, and a related but inappropriate word comes repeatedly or persistently to mind, and must be rejected. Older adults rate TOTs as their most common problem with expressive language (Ryan et al. 1994), and their performance is consistent with these ratings: Both naturally occurring and experimentally induced TOTs increase with age, as shown in table 1. Older adults, however, report fewer phonological features of the target word and fewer persistent alternate words than do young adults (Cohen & Faulkner 1986; Maylor 1990; Burke et al. 1991; Rastle & Burke 1996).

Insert table 1 here

At least three additional forms of evidence indicate age-related declines in word production. One is older adults' slower and less accurate picture naming (e.g., Mitchell 1989; Au 1995), which appears to reflect a deficit in access to the phonological information associated with words because providing phonological cues to the word reduces the age deficit (e.g., Thomas et al. 1977). A second source of evidence for age-related declines in word production concerns use of pronouns in spontaneous speech: Relative to young adults, older adults generate more pronouns than common or proper nouns, and more ambiguous references, apparently because older adults were less able than young adults to retrieve the appropriate nouns (e.g., Pratt et al. 1989; Cooper 1990; Heller & Dobbs 1993). Third, disfluencies in speech such as word repetitions and prolonged pauses (filled and unfilled) increase with age, phenomena often associated with word retrieval difficulties (Cooper 1990; Kemper 1992a). Overall, these word production deficits suggest that unlike retrieval of word meaning, which seems to be well preserved in old age, the ability to retrieve the sound or phonology of words declines with ageing. We now discuss a corresponding deficit in retrieving another aspect of the physical form of words; spelling.

Asymmetries in spelling perception versus production

Recent data comparing the perception versus production of spelling patterns (MacKay et al. 1997) illustrates clearly and dramatically the asymmetry in effects of ageing on perception versus production of language. In one experiment, young (age 17-23 years), older (age 60-71 years), and very old participants (age 73-88 years) listened to English words with irregular spellings, spoken clearly at a relatively slow rate, and simply wrote them down at their own pace on a sheet of paper. The words were either relatively common in English, e.g., rhythm, or relatively rare, e.g., chauffeur. Despite having more education and higher vocabulary scores, the oldest adults correctly spelled the common words less often than did young adults. Because trials were self-paced, response speed was de-emphasized, and the stimuli were presented slowly and repeatedly in this experiment, the spelling errors that occurred can be considered long term errors rather than transient or correctable Òslips of the pen.Ó In addition, the age-linked decline in correct spelling was unrelated to prior training on spelling skills, and hours per week spent reading, writing, solving crossword puzzles, or other activities involving spelling.

A second experiment in MacKay et al. (1997) replicated the age-linked decline in producing the spelling of familiar words, but showed that perceiving spelling patterns remains constant in old age. This experiment provides the first demonstration of age-linked asymmetries between perception versus production for the same stimuli and the same participants in equally difficult perception versus production tasks. Young and older adults with normal or corrected-to-normal vision saw common words, presented briefly at a range of different exposure durations on a computer monitor. Some of the words were misspelled by adding or substituting a single letter, e.g., endeavor misspelled as endeavuor, and participants had two tasks. The first was a perception task: to respond ÒrightÓ to indicate correct spelling or ÒwrongÓ to indicate incorrect spelling. The second was a production task: to write out the spelling of the word, exactly as presented on the screen.

The perceptual task indicated that recognizing correct or incorrect spelling did not decline with age (see the left panel of figure 2). These data are consistent with the frequently observed small or nonexistent age effects for language perception discussed earlier. However, age differences occurred in the production task (see the right panel of figure 2). Older adults correctly reproduced the incorrectly spelled words less often than young adults, even when both groups indicated awareness that these stimuli were misspelled. Older adults also correctly reproduced correctly spelled words less often than young adults (see figure 2, right panel), despite awareness that these stimuli were correctly spelled. Together with the TOT data, these spelling deficits indicate that information about the orthography and phonology of words becomes more difficult to retrieve with age. However, the spelling data indicate age-linked declines in retrieving frequently used words, and not just words that that have been rarely or not recently used, as has been shown for TOTs (see Burke et al. 1991).

Insert figure 2 about here

Summary
Experimental evidence over the last 20 years strongly supports the Òclassic ageing patternÓ observed originally in intelligence test performance. That is, performance IQ scores that depend on new learning and speed of processing, so-called fluid intelligence, decline in old age, whereas verbal IQ scores that depend on language comprehension, vocabulary, and world knowledge, so-called crystallized intelligence, remain relatively constant in old age (Horn 1982; Botwinick 1984). However, recent experiments have contradicted the hypothesis that verbal abilities are preserved across the board in old age. Older adults exhibit clear deficits in the retrieval or production of phonology and

orthography. The current picture of cognitive ageing therefore includes deficits in new learning and in the production of phonology and orthography, with no corresponding deficits in the perception and comprehension of language independent of sensory and new learning deficits.

This emerging pattern presents a fundamental challenge for theories of cognitive ageing, which must explain why some aspects of the language memory system are so much more vulnerable to effects of ageing than others. In particular, why are there age-linked deficits in new learning and in some aspects of language production involving familiar information, but not in the perception and comprehension of familiar information? A decremental approach to theory construction that addresses only the deficits in cognitive ageing and leaves unspecified the mechanisms underlying preserved cognitive functions is no longer a viable option.

Theories of Cognitive Ageing

How well do existing theories of ageing, memory and language fit the general pattern of spared and impaired memory functions outlined above? Table 2 lists some comprehensive theories that have been applied to memory and language in old age, and sorts these theories into two categories: information-universal versus information-specific theories. The mechanism underlying cognitive ageing in information-universal theories is independent of the type or structure of the information being processed, unlike information-specific theories, where the type or structure of the memory units plays an important role in the effects of cognitive ageing. The list of theories in table 2 is not meant to be exhaustive (see e.g., review of theories in Light 1991; Craik & Jennings 1992; Salthouse 1996; Smith 1996), but will serve to illustrate the significance of the new pattern of spared and impaired functions that must be considered in developing viable theories of cognitive ageing.

Insert table 2 here

Information-universal Theories

General Slowing theories are the oldest and most extensively researched of the information-universal theories, which postulate effects of ageing that are independent of the type or structure of the information being processed. Under General Slowing theories, the speed of executing cognitive operations decreases with ageing, regardless of the type of task or the mental operations involved in the task (e.g., Birren 1965; Cerella 1990; Myerson et al. 1990; Salthouse 1985, 1996). This general slowing assumption readily captures two types of empirical generalization. One is that older adults are slower on virtually all cognitive tasks regardless of the psychomotor requirements of the task. The other is that in adulthood, perceptual-motor reaction times correlate highly with errors in performance on a broad range of tasks involving new learning, speeded performance, or both, including working memory, free recall, and verbal fluency tasks.

Salthouse (1996) proposed two mechanisms through which general slowing may cause errors and disrupt performance. First, some cognitive operations may be executed too slowly for successful completion in the time available, causing an increase in errors. Second, information from different sources may become available to a central processor so slowly that the earlier information has decayed or is no longer active by the time the later information arrives. As a result, cognitive operations that depend on the simultaneous availability of both sources of information can no longer be executed. This second mechanism would cause errors even in tasks without time constraints.

The problem that this and other General Slowing theories must address is that whereas age-related slowing is ubiquitous or universal in the theory, deficits in cognitive performance, as we have seen, are not. Why is cognitive performance intact in old age for language comprehension and other semantic tasks, even though older adults perform these tasks more slowly than young adults? For example, why are word association responses identical in type and distribution as a function of age, even though the time to produce these word associations are longer for older than young adults (Burke & Peters 1986)? General Slowing theories provide no answer. As Salthouse (1996) suggested, an adequate explanation of the pattern of spared and impaired abilities in old age may require specific, local mechanisms, in addition to a general slowing mechanism.

The Inhibition Deficit hypothesis is a rather different type of information-universal theory which assumes that inhibitory processes decline with ageing regardless of the type or structure of the units on which these inhibitory processes operate. That is, under the Inhibition Deficit hypothesis, ageing impairs the inhibition of irrelevant information in all memory systems. To illustrate one of the empirical phenomena to which the Inhibition Deficit hypothesis has been applied, people in the TOT state often report that irrelevant words come to mind spontaneously and repeatedly instead of the intended or target word, as if these persistent alternates are causing the TOT by preventing retrieval of the target word. Under the Inhibition Deficit account, older adults are less able to inhibit irrelevant information, in this case, the alternate words, and therefore experience more TOTs than young adults. However, several age-linked aspects of the TOT experience contradict this Inhibition Deficit hypothesis. Older adults report fewer persistent alternates than young adults during TOTs either in everyday life or induced in the laboratory (see table 1). If older adults suffer more TOT experiences because of greater competition from the alternate words, then they should report more alternates than young adults. Instead, older adults in the throes of a TOT report fewer alternates and less information of any kind about the target word, saying that their mind simply goes blank (Burke et al 1991; Cohen & Faulkner 1986).

The Inhibition Deficit hypothesis has also been applied to age-linked deficits in episodic recall. Under this account, older adults suffer increased interference from irrelevant information, which disrupts the encoding and retrieval of relevant episodic information (e.g., Hasher & Zacks 1988; Zacks & Hasher 1994). Unfortunately, the postulated interference from irrelevant information in the

Inhibitory Deficit hypothesis also occurs during retrieval of word meaning in semantic processing, predicting age-linked decrements in language comprehension and in semantic memory tasks. As noted earlier, however, older adults do not show signs of allowing irrelevant information to intrude in word association and semantic priming tasks (Burke in press).

Information-specific Theories

Region Specific Neural Ageing hypotheses represent one approach to developing an information-specific theory of cognitive ageing, where the effects of ageing depend on the type or structure of the underlying representational or memory units. Region Specific Neural Ageing hypotheses link neurobiological changes in the brain to the pattern of spared and impaired cognitive functions in old age. Two converging strategies have been followed in developing such hypotheses. One strategy is to use techniques such as neuroimaging to directly measure the integrity of neuroanatomical structures as a function of ageing (see e.g., Madden & Hoffman 1997). If specific regions of the brain are more prone to neurobiological changes with ageing, then effects of cognitive ageing can be postulated based on the known cognitive functions of these brain regions. For example, using magnetic resonance imaging (MRI) scans to measure volume of the hippocampus, Golomb et al. (1993) reported a correlation between episodic memory performance and loss of hippocampal volume in older adults. Other MRI researchers, however, have failed to find age-related decreases in hippocampal volume (e.g., Raz et al. 1993).

A second strategy within the Region Specific Neural Ageing framework is to compare the deficits of older adults and patients with focal lesions in specific regions of the brain: If the deficits match, then the hypothesis is that these particular brain regions are more vulnerable to effects of ageing than other areas of the brain. Amnesic patients with lesions in the hippocampus and associated medial temporal cortex have been a salient comparison group. Like older adults, amnesics show normal repetition priming effects despite profound impairment on explicit memory tasks, which suggests that the hippocampus and associated medial temporal regions are especially impacted by normal cognitive ageing (see Moscovitch & Winocur 1992). Patients with focal lesions in the frontal lobes have been another comparison group for developing Region Specific Neural Ageing hypotheses. For example, Stuss et al. (1996) noted a parallel between the memory performance of older adults and patients with unilateral lesions in right frontal regions: Both groups showed a decline in explicit recall and in measures of organizational strategies believed to be helpful in recall, but no decline in recognition memory tasks. Stuss et al. therefore argued that normal ageing impairs the functioning of right frontal regions, which in turn reduces recall by impairing organizational strategies. This argument was weakened, however, by the finding that the frontal patients displayed additional organizational impairments that were not seen in older adults, for example, repeating the same word in recall of a list.

Another parallel between older adults and patients with frontal lobe damage is that both groups perform more poorly than controls on fluency tests and on the Wisconsin Card Sort test, suggesting that the frontal lobes are especially impacted by ageing (e.g., Arbuckle & Gold 1993). However, this argument is weakened by evidence that such tests are sensitive to general cognitive functions such as perceptual speed, and not just specific functions of discrete anatomical structures such as the frontal lobes (Salthouse et al. 1996). In short, region-specific effects of ageing are currently controversial and require further research before they can account for the pattern of cognitive aging that we have observed.

Empirical issues aside, Region Specific Neural Ageing hypotheses also face several unresolved theoretical issues. The main unresolved issues are why and exactly how ageing impairs the functioning of the hippocampus and frontal lobes more so than other areas of the brain. Another unresolved issue concerns the explanation of phenomena such as general slowing which apply across the board, and are not restricted to functions envisioned for the hippocampus and frontal lobes.

The Transmission Deficit hypothesis provides an account of general slowing (see MacKay & Burke, 1990), but represents a quite different approach to developing an information-specific theory. Under the Transmission Deficit hypothesis, encoding of new memories and retrieval of existing memories depends on the rate of transmission of priming across the connections linking representational units in memory. Priming is a form of subthreshold excitation that prepares a unit for activation or retrieval, and the rate of priming transmission depends on the strength of connections among units. Connections become stronger with use (activation), and especially recent use, and weaken over time as a result of disuse. Most important, ageing is postulated to weaken connection strength. The transmission deficits that result when relevant connections become especially weak have effects that vary depending on the architecture and processes of the memory system involved, which enables the theory to account specifically for the small effects of ageing on the perception and comprehension of language, and for the large effects of ageing on new learning and on the production of orthography and phonology (e.g., MacKay 1987; MacKay & Burke 1990; Burke et al. 1991; MacKay & Abrams 1996). To understand this account therefore requires a detailed look at the architecture and processes underlying language and memory in the theory.

Like other current interactive activation models of memory, the Transmission Deficit hypothesis postulates a vast network of pathways connecting representational units called nodes. Nodes are organized into a semantic system which represents the meanings of words and propositions, a phonological system which represents speech sounds and syllables, and an orthographic system which represents letters and other orthographic units (MacKay 1987). Figure 3 illustrates the specific nodes in the semantic and phonological systems for comprehending and producing a familiar word such as frisbee. Reading or hearing the word frisbee transmits priming bottom-up via many orthographic and/or phonological connections that all converge onto a single lexical node, and activation of this lexical node constitutes comprehension of the word frisbee. However, in producing the word frisbee, priming is transmitted top-down to the lexical node for frisbee, which when activated, transmits top-down priming simultaneously to many phonological nodes. This diverging characteristic of top-down connections for producing the phonology of words is a direct consequence of the hierarchical organization of nodes, and increases the likelihood of errors due to transmission deficits. Because each phonological node must receive sufficient priming from its single top-down connection in order to become activated, a transmission deficit in that particular connection will prevent activation of that node. However, the converging characteristic of bottom-up connections for perception can offset an age-linked transmission deficit in any one connection. Receiving summated priming from many phonological connections, the appropriate lexical node will achieve sufficient priming in order to become activated despite the transmission deficit in any one connection. Because of this asymmetry in the structure of bottom-up vs. top-down processes, the Transmission Deficit hypothesis predicts small or non-existent ageing effects for perceptual tasks, but large age-linked deficits for production tasks, including the production of spelling.

Insert figure 3 here

Semantic priming effects further illustrate how the structure of connections within a memory system can determine whether age-linked transmission deficits distributed throughout the interactive activation network become manifest in behavior. Semantic priming effects remain intact in older adults because priming summates over the large number of connections that link semantically related concepts in memory (see MacKay & Burke 1990), thereby offsetting the effect of age-linked transmission deficits in any one connection (Laver & Burke 1993; MacKay & Abrams 1996). When a task requires transmission of priming across a single critical connection, however, priming summation across multiple connections cannot compensate for the deficit in priming transmission that distinguishes older from young adults. This concept of a single critical connection is readily illustrated via word retrieval failures such as TOTs. In general, phonological nodes are hierarchically linked to one another via only a single top-down connection and so receive a single source of priming without the possibility of summation across multiple connections, as typically occurs within the semantic system. TOTs originate when the lexical node for a target word becomes activated through top-down priming, but deficits in priming transmission make one or more of its connected phonological nodes impossible to activate. Inasmuch as age reduces the transmission of priming, older adults will experience more TOT states and retrieve less phonological information about the target and fewer persistent alternates, as has been observed (see table 1)

Within the Transmission Deficit framework, new learning is in general difficult for older adults because new connection formation requires higher than normal levels of priming transmission. New connections among memory representations are only created and maintained after prolonged transmission of priming, so that this priming-intensive process is especially susceptible to transmission deficits. In contrast, retrieving existing memories requires relatively little transmission of priming, especially for memories involving strong connections that have been recently or frequently activated in the past and receive help from converging connections within the memory system (see MacKay & Burke 1990).

Summary
All of the theories in Table 2 are in the early stages of development. All can explain some aspects of the available data on cognitive ageing, but all are in need of further development and tests that focus not on confirming results, but on points of theoretical weakness. These points of weakness are perhaps clearest in the case of information-universal theories which have concentrated on cognitive decline in old age and therefore require additional mechanisms to account for the pattern of preserved cognitive functions, e.g., in implicit but not explicit tests of memory, and in language comprehension but not language production. Such differential aging patterns come built into Information-specific theories such as Region Specific Neural Ageing, but these theories have the inverse problem of explaining phenomena such as general slowing that are not region-specific. And although the Transmission Deficit hypothesis does not have this particular problem, it is too soon to tell whether this theory will withstand direct empirical tests.

Practical Implications of Cognitive Ageing Research
The emerging pattern of spared and impaired functions in cognitive ageing research carries important practical implications. One concerns the beneficial effects of practice during old age. From the theoretical perspective of the Transmission Deficit hypothesis, activation strengthens connections among existing memory representations in both young and older adults, increasing the ease of subsequent retrieval. On the other hand, rare or nonrecent activation reduces connection strength. These theoretical principles suggest a Òuse it or lose itÓ maxim for preserving knowledge and skills during old age. Even the expert performance of professional pianists can be largely preserved in old age through practice (Krampe & Ericsson 1996). Moreover, research using the implicit memory paradigms reviewed earlier shows that practice or repetition improves performance of young and older adults to a similar extent. Repetition even reduces the likelihood of retrieval failures involving specific words: Young and older adults are almost 50% less likely to experience a TOT for proper names and other words that they produced in an unrelated prior task compared to a condition with no prior task (Rastle & Burke 1996).

In short, both theoretical and empirical research point to the importance of intellectual stimulation and continued use of language skills and knowledge in old age. This implies that when communicating with older adults, speakers should not revert to oversimplified speech or baby talk. Such ÒelderspeakÓ carries negative and inaccurate connotations regarding the language abilities of older adults, and could promote withdrawal from verbal interaction, undermining older adults' efforts to maintain their language skills (Kemper 1992b; Ryan et al. 1994; Small et al. 1997).

Related practical implications derive from the fact that, once learned, skills and knowledge are largely preserved in old age, unlike new learning. Consequently, older adults can maximize their cognitive functioning by using familiar skills and knowledge acquired over a lifetime. This point is nicely illustrated by the findings of Shimamura and colleagues, who compared the cognitive performance of young and older college professors ranging in age from 30 to 71 years on the faculty at the University of California at Berkeley (Shimamura et al. 1995). The older professors showed the usual age-related slowing on a standard response time task and the usual age-related decrement on an episodic memory task that required the formation of new associations between word pairs, in this case arbitrarily chosen proper names. However, young and older professors did not differ in their ability to learn conceptual information of the sort that they had encountered throughout their careers, e.g., fictional prose, a scientific text about the earth's atmosphere, or an anthropological-historical text about native tribes. By contrast, a comparison of young and older adults who were not professors and lacked experience processing this type of information showed the standard age-related decline in learning this same material.

These findings suggest that over their lifetimes, the older professors had developed sophisticated reading, analytic, and organizational skills and had acquired detailed knowledge structures within which relevant information could be readily assimilated. These skills and knowledge structures facilitated the acquisition of relevant information, thereby eradicating the usual age-linked declines in new learning (see Bosman & Charness 1996, for a discussion of other mechanisms underlying preserved function in cognitive skills). Parallel findings have been reported for young and older pilots who did not differ in recall of air traffic control communication, whereas the usual age deficit was obtained with young and older non-pilots (Morrow et al., 1994). In short, older adults should expect declines in learning novel information that is irrelevant to organizational and analytic skills, like the older professors learning arbitrarily paired words. Older adults can, however, offset such effects of cognitive ageing by focusing on the domains of intellectual expertise that they have developed over their lifetimes.

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Table 1. Mean Number of TOTs and Percent of TOTs with Persistent Alternates in Experimentally Induced and Naturally Occurring TOTs

	Age Group	**Mean nmbr of TOTs**	**% w/Persistent Alternates**
Naturally Occurring TOTs	Young	3.9a	67%
	Midage	5.4	58%
	Old	6.6	48%
Lab Induced TOTs	Young	10b	41%
	Old	12	10%

Young	5c
Old	11

Example TOT Words	Example Persistent Alternates
mausoleum	mortuary
eccentric	exotic
pomegranate	persimmon
blender	vibrator

a During one month; Burke et al. 1991
b For 100 questions; Burke et al 1991
c For 90 questions; Rastle & Burke 1996

Table 2. Examples of Theories of Cognitive Ageing in Two General Categories

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Information Universal Theories

- General Slowing (e.g., Salthouse 1985, 1996)
- Sensory Decline (e.g., Lindenberger & Baltes 1994)
- Inhibitory Deficits (e.g., Hasher & Zacks 1988)

Information Specific Theories

- Transmission Deficits (e.g., MacKay & Burke 1990)
- Encoding Deficits (e.g., Craik & Jennings 1992)
- Region Specific Neural Ageing (e.g., Moscovitch & Winocur 1992; Shimamura 1994)

FIGURE CAPTIONS

Figure 1. Performance on three memory tests expressed as a percentage of the maximum score obtained at any age. Action memory and sentence memory required episodic recall of presented material whereas general knowledge required recall of semantic or world knowledge (adapted from Nyberg et al. 1996).

Figure 2: Percent correct detection (left panel) and written spelling production (right panel) of correctly and incorrectly spelled words as a function of age group (adapted from MacKay et al. 1997).

Figure 3: An example of the memory representation of semantic and phonological information corresponding to the word frisbee. Many nodes necessary for perceiving or producing this word have been omitted to simplify the figure.