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Theoretical Approaches to Language and Aging

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Research on cognition and aging has developed rapidly over the past several decades, moving beyond its early focus on psychometric intelligence tests to encompass new experimental paradigms and theoretical frameworks from cognitive psychology and the neurosciences. Although the accumulation of empirical findings has overshadowed the development of theories for explaining the patterns of cognitive change in old age, specification of theories of cognitive aging has undergone recent progress (e.g., Bowles, 1994; Byrne, 1998; Hasher & Zacks, 1988; MacKay & Burke, 1990; Myerson, Hale, Wagstaff, Poon & Smith, 1990; Salthouse, 1996). In this chapter, we describe a detailed theory of cognitive aging, the Transmission Deficit hypothesis, comparing it to other theories and demonstrating its account of evidence relating aging and language. We start with evidence indicating that effects of aging on language comprehension versus production are asymmetric, a phenomenon that sets a boundary condition for theories of cognitive aging. Although theories of cognitive aging have in general focused on cognitive decrements, these asymmetries indicate that they must also account for domains of performance that are preserved in old age, such as language comprehension. We compare two classes of cognitive aging theories for explaining asymmetric effects of aging on language: information-universal and information-specific theories. Then we provide a detailed account within the Transmission Deficit model of how aging impacts three aspects of language production: tip of the tongue experiences, proper name recall and retrieval of orthographic knowledge.

Patterns of Language Performance in Normal Aging

One empirical generalization that emerged from early research on cognitive aging was that language processing was spared in old age, especially when compared to the decline in “fluid”

intellectual abilities, such as remembering new information (e.g., Botwinick, 1984). The last 20 years of research on aging and language, however, has revealed a more complex pattern, with asymmetric aging effects on input versus output processes. The input side of language includes perception of the letters and speech sounds that make up words, and retrieval of semantic and syntactic information about words and sentences. These input-side processes are frequently referred to as "language comprehension," and they remain remarkably stable in old age, independent of age-linked declines in sensory abilities (Madden, 1988) and memory for new information (Light & Burke, 1988; Kemper, 1992b; Tun & Wingfield, 1993). Indeed, tasks highlighting comprehension processes, such as general knowledge and vocabulary tests, provided much of the data for earlier conclusions about age constancy in language processes. The output side of language involves retrieval of phonological and orthographic components of words and their production in speaking or writing. These output-side processes, commonly termed "language production," do show age-related performance declines. In the next sections, we present empirical evidence for these asymmetric effects of aging on language processes.

Language Comprehension and Aging

Aging has little effect on the representation of semantic knowledge as revealed, for example, by word associations (e.g., Burke & Peters, 1986), script generation (e.g., Light & Anderson, 1983) and the structure of taxonomic categories (Howard, 1980; Mueller, Kausler, Faherty & Oliveri, 1980). Because comprehension involves mapping language onto existing knowledge structures, age constancy in the nature of these structures is important for maintaining language comprehension in old age. There is no age decrement in semantic processes in comprehension as measured via on-line techniques. Probably the most popular of these on-line measures is the semantic priming effect, the reduction in the time required to identify a target

word, say, TEACHER, when it follows a semantically related word, e.g., STUDENT, rather than a semantically unrelated word, e.g., GARDEN. Even when participants cannot develop expectancies concerning related words or when the interval between prime and target is too brief for attentional effects, semantic priming effects can be attributed to automatic activation of meaning during perception of the prime word, and spread of excitation (priming) to semantic representations of related words, making them easier to activate. Thus, perception of STUDENT primes semantically related information, speeding recognition of TEACHER; and such semantic priming effects are at least as large in older as young adults (e.g., Balota, Black & Cheney, 1992; Burke, White & Diaz, 1987; see meta-analyses by Laver & Burke, 1993 and Myerson, Ferraro, Hale & Lima, 1992). The same is true of mediated semantic priming effects, which are measured for prime words that are related to target words only through another *unpresented* word that is related to both prime and target, e.g., prime word: LION (related to mediating word:TIGER), target: STRIPES. For both young and older adults, recognition of STRIPES is faster following LION, rather than a completely unrelated word, an effect attributed to priming triggered by activation of LION and transmitted through TIGER to STRIPES (Bennett & McEvoy, in press). These mediated priming effects indicate how far priming spreads in semantic networks and provide further evidence for age constancy in transmission of semantic priming within a network.

Semantic priming effects also provide a measure of semantic processing during silent reading of sentences: Participants identify the target word BOOKS more quickly and accurately in a common context (e.g., The accountant balanced the BOOKS), than in an uncommon context, e.g., The train went over the BOOKS (Madden, 1988), and facilitation from common contexts is at least as large for older as for young adults (Burke & Yee, 1984; Cohen & Faulkner, 1983; Nebes, Boller, & Holland, 1986; Stine & Wingfield, 1994; Wingfield, Alexander, & Cavigelli,

1994). There is also no age decrement in drawing correct inferences during reading or in specifying particular word meanings implied by the context (Burke & Harrold, 1988; Burke & Yee, 1984; Hamm & Hasher, 1992; Light, 1991; Light, Valencia-Laver & Zavis, 1991), except when working memory deficits intervene (e.g., Light & Capps, 1986).

In a meta-analysis of age effects on direct and indirect measures of memory, Light, Prull and La Voie (this volume) found that latency measures of repetition priming effects were age invariant while accuracy measures showed age-related declines in repetition priming effects. This disparity is theoretically interesting because general slowing models of cognitive aging predict larger repetition priming effects for older adults using latency measures because of older adults' longer overall latencies; if older adults are less responsive to repetition, as suggested by their smaller repetition effects on indirect measures involving accuracy, than on indirect measures involving latency, their increased latencies due to general slowing may compensate for smaller repetition effects so that the change in latency produced by repetition (priming effect) may appear to be age-invariant.

This asymmetry in age effects for latency and accuracy measures does not hold for semantic priming effects. An informal comparison of effects in semantic priming studies showed that these effects were at least as large for old as for young adults both with accuracy measures (e.g., Cohen & Faulkner, 1983; Hutchinson, 1989; Stine & Wingfield, 1994; Wingfield et al., 1994; Wingfield, Aberdeen & Stine, 1991) and latency measures (for meta-analysis, see Laver & Burke, 1993). Thus repetition priming effects and semantic priming effects appear to be differently affected by age.

Studies using "on-line" techniques rule out a major confound inherent in "off-line" 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 "off-line" tasks (e.g., Hamm & Hasher, 1992; Hartley, 1988; Hartman & Hasher, 1991), but have less to do with initial comprehension than with memory for the comprehended information (see e.g., Burke, 1997; Stine, Soederberg, & Morrow, 1996). Results of off-line studies seem to reflect an age-related deficit in remembering the link between comprehended information and its source or context. When episodic memory is factored out, evidence for age constancy in language comprehension and in the structure and retrievability of general knowledge is both strong and consistent (Burke, 1997; Kemper, 1992b; Light, 1991; MacKay & Abrams, 1996; MacKay & Burke, 1990; Tun & Wingfield, 1993).

Language Production and Aging

In contrast to the age constancy in comprehending word meaning, extensive experimental research shows age-related declines in retrieving a word corresponding to a meaning or a picture, and so does older adults' self reports. Older adults rated word finding failures and tip of the tongue experiences (TOTs) as cognitive problems that are both most severe and most affected by aging (Rabbitt, Maylor, McInnes, Bent & Moore, 1995; Ryan, See, Meneer, & Trovato, 1994; Sunderland, Watts, Baddeley, & Harris, 1986). Older adults rated retrieval failures for proper names as especially common (Cohen & Faulkner, 1984; Martin, 1986; Ryan, 1992) and the most annoying, embarrassing and irritating of their memory problems (Lovelace & Twohig, 1990).

Older adults' performance in language production experiments confirm their self reports. Compared to young adults, older adults are slower and less accurate in producing names for definitions or pictures (e.g., Au et al., 1995; Bowles & Poon, 1985; Nicholas, Obler, Albert & Goodglass, 1985; see Goulet, Ska & Kahn, 1994 for a review). They also produce more ambiguous references and pronouns in their speech, apparently because of an inability to retrieve

the appropriate nouns (e.g., Cooper, 1990; Heller & Dobbs, 1993; but see Glosser & Deser, 1992). Speech disfluencies such as filled pauses and hesitations increase with age and may likewise reflect word retrieval difficulties (Cooper, 1990; Kemper, 1992a). Finally, TOT states increase with aging, one of the most dramatic instances of word finding difficulty in which a person is unable to produce a word although absolutely certain that they know it. Both naturally occurring (Burke, MacKay, Worthley & Wade, 1991) and experimentally induced TOTs (Burke et al., 1991; Brown & Nix, 1996; James & Burke, 1998; Maylor, 1990b; Rastle & Burke, 1996) increase with aging. As we discuss in detail below, word retrieval failures in young and especially older adults appear to reflect declines in access to phonological representations.

Evidence for age-linked declines in language production has come almost exclusively from studies of word retrieval. Recently, however, MacKay and Abrams (in press; MacKay, Abrams & Pedroza, in press) reported some important new age-related production deficits that were unanticipated in previous experimental studies and self report questionnaires: Older adults made certain types of spelling errors[1] more often than young adults in written production, a sub-lexical retrieval deficit involving orthographic units. This decline occurred despite age equivalence in the ability to detect spelling errors and despite the higher vocabulary and education levels of older adults.

The phonological/orthographic retrieval problem in old age 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 and orthographic forms. Thus, unlike comprehension of word meaning, which seems to be well preserved in old age, retrieval at phonological and orthographic levels of representation declines with aging. This asymmetric

pattern of aging effects for comprehension versus production provides fertile testing ground for theoretical accounts of cognitive aging, as we discuss next.

Theories of Cognitive Aging

Comprehensive theories that can be applied to language and aging fall into two categories: information-universal versus information-specific theories. In information-universal theories, the mechanism underlying cognitive aging is independent of the type or structure of the information being processed, unlike information-specific theories, where the type or structure of language units plays an important role in aging effects.

Information-universal Theories

General Slowing theories postulate aging effects that are independent of the type or structure of the information being processed and represent the oldest and most extensively researched of the information-universal theories. Under General Slowing theories, the speed of executing cognitive operations decreases with aging regardless of the task or the mental operations involved in the task (e.g., Birren, 1965; Cerella, Poon & Williams, 1980; Myerson et al., 1990; Salthouse, 1985, 1996). A variant of this general slowing assumption holds that age-related slowing remains constant across all tasks within a "domain", but not across different task domains, for example, lexical vs. spatial tasks (e.g., Cerella, 1985; Lima, Hale & Myerson, 1991).

General slowing assumptions are compatible with two types of empirical generalization. One is that across the lifespan, perceptual-motor reaction times correlate highly with errors in performance on a broad range of tasks involving new learning or speeded performance, for example, working memory, free recall, and verbal fluency tasks (e.g., Salthouse, 1985). The second compatible generalization is that older adults are slower on many cognitive tasks regardless of the psychomotor requirements of the task. Indeed, some researchers have used

Brinley plot analyses to argue for a universal general slowing factor. When older adults' mean latency is plotted as a function of young adults' mean latency in the same condition, regression analyses have revealed a consistent mathematical relationship between young and older adults' response latency for a variety of tasks (e.g., Cerella, 1990; Lima et al., 1991; Myerson et al., 1992).

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 available time, 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 an age-linked increase in errors even for tasks without time constraints.

This and other General Slowing theories must address two interrelated issues. One is that age-related slowing is universal in these theories, whereas deficits in language performance are not. General Slowing theories require a principled basis for explaining the asymmetric effects of aging on the input versus output side of language, for example, the preserved detection of spelling errors and impaired production of correct spelling (MacKay et al., in press), or the preserved interpretation of word meaning and impaired production of words (Burke et al., 1991; see Salthouse, this volume for a general slowing account of asymmetrical age effects). Explaining why some aspects of language remain intact in old age, even though older adults perform these tasks more slowly than young adults, provides a related challenge for General Slowing theories. For example, even though older adults require more time to produce word associations than young

adults, word association responses are identical in frequency and type across age (Burke & Peters, 1986), an asymmetry that is unpredicted by General Slowing theories.

The second issue that General Slowing theories must address is methodological in nature and concerns the almost exclusive reliance on Brinley plots and regression analyses. With older adults' latency plotted as a function of young adults', several studies have reported a consistent linear function with a slope greater than 1.0 (e.g., Lima et al, 1991; Madden, 1989; Cerella et al., 1980). However, this consistency in slope across conditions is in part a consequence of the insensitivity of regression techniques to variation across conditions (Fisher, Fisk & Duffy, 1995; Fisk & Fisher, 1994; Perfect, 1994). Moreover, conclusions about general slowing based on such analyses assume isomorphism between the processes that young and older adults use to perform the task, an assumption that has proven invalid (see Fisher et al., 1995; Rogers & Fisk, 1990; Stine, 1995). Finally, a growing number of Brinley-plot *exceptions* to a slowing factor greater than 1.0 require explanation: Meta-analytic studies have reported old:young ratios approximating 1.0 for reading time (Stine, 1995), for implicit memory tasks (see chapter this volume by Light, Prull & LaVoie) and for semantic priming effects (Laver & Burke, 1993; see also Fisk & Rogers, 1991). Thus, the slowing factor exhibits considerable variation, even within a single domain such as verbal performance.

The *Inhibition Deficit* hypothesis is a rather different type of information-universal theory which assumes that aging weakens inhibitory processes associated with task-irrelevant information. That is, older adults are assumed to activate more irrelevant information than young adults and suppress less irrelevant information once it is activated, regardless of the type or structure of the irrelevant information. Under this hypothesis, aging impairs inhibition in all cognitive systems, including attention, memory, and language, and this disrupts use of relevant

information (Hasher & Zacks, 1988; Zacks & Hasher, 1994, 1997). Studies showing greater behavioral interference for older than young adults in a variety of tasks have been cited as evidence for such age-related inhibitory deficits. For example, relative to young adults, older adults show more interference from the inconsistent color baseword in the Stroop color naming task (e.g., Spieler, Balota & Faust, 1996), and from superimposed, distracting words when reading sentences (Connelly, Hasher & Zacks, 1991) or processing pictures (Bowles, 1994; Duchek, Balota, Faust & Ferraro, 1995).

However, inhibition has proven elusive as a theoretical concept because behaviorally defined inhibition (negative priming and Stroop interference effects) does not necessarily entail theoretical inhibition and alternative, non-inhibitory accounts have been offered for behavioral inhibition effects (e.g., Burke, 1997; Dywan & Murphy, 1996; Hartman, 1995; Kieley & Hartley, 1997; Wheeldon & Monsell, 1994). Even for behaviorally defined inhibition, age differences have been consistently obtained neither for Stroop interference (Verhaeghen, this volume) nor negative priming effects (e.g., McDowd, 1997), and neither negative priming nor Stroop interference effects correlate well with other tasks showing age differences hypothesized to depend on inhibition (e.g., Christidis & Burke, 1998; Kramer, Humphrey, Larish, Logan & Strayer, 1994; Shilling & Rabbitt, 1998; but see Kwon See & Ryan, 1995).

Because of its information-universal nature, the Inhibition Deficit hypothesis is also incapable of explaining asymmetric effects of aging on input versus output processes. If, as Hasher & Zacks (1988) assume, inhibition is an essential component of both the comprehension and production of language, age decrements should occur for both. Because the incompatibility of Inhibition Deficit theory with age constancy in comprehension processes has been well documented (Burke, 1997), we will focus here on an aspect of language production that does

show age changes, and has been claimed to support the Inhibition Deficit hypothesis. This aspect is off-topic speech.

Verbosity, or the production of prolonged and redundant speech that is irrelevant to the current topic, increases with aging according to Arbuckle & Gold (1993) and Gold, Andres, Arbuckle & Schwartzman (1988). The explanation offered by the Inhibition Deficit hypothesis is that older adults' reduced ability to inhibit irrelevant information makes it difficult or impossible for them to suppress thoughts that digress from the current speech topic, resulting in production of extraneous personal observations and unrelated information in their speech (Arbuckle & Gold, 1993; Zacks & Hasher, 1994). Two aspects of the empirical findings, however, challenge the Inhibitory Deficit explanation. First, age differences in off-topic speech are obtained in some contexts, e.g., when describing autobiographical information (Arbuckle & Gold, 1993; James, Burke, Austin, & Hulme, 1998) but not in others, e.g., when describing pictures (Cooper, 1990; James et al.,1998) or when describing a vacation (Gould & Dixon, 1993). Inasmuch as inhibitory deficits are information-universal, they should influence all speech and it is unclear how they can explain why older adults wander off-topic for some topics but not others.

A second problematic finding for the inhibition deficit hypothesis is that evaluative ratings are more favorable for older adults' than young adults' speech (e.g., James et al., 1998; Kemper, Rash, Kynette, & Norman, 1990). In James et al., young and older raters read transcribed descriptions of autobiographical events and rated older adults' descriptions more positively than young adults', even though older adults strayed off topic more frequently than young adults. When the older speakers were divided into high- and low-verbosity groups based on the amount of off-topic speech they generated, ratings of the descriptions were more favorable for the high- than low-verbosity group. Thus, increased off-topic information appears to

increase, not decrease, the communicative value of older adults' speech. This is paradoxical under the Inhibition Deficit model which claims that off-topic speech reflects a cognitive impairment. Deepening the paradox, older adults' off-topic speech also failed to impair performance on a problem solving task that required effective communication for success (Arbuckle, Pushkar, Nohara-LeClair, Basevitz & Peled, 1998).

To explain these off-topic speech results, the Inhibition Deficit hypothesis must either modify its system-wide inhibitory decrement assumption, or specify additional mechanisms to account for the topic-specificity and high communicative value of older adults' off-topic speech. Moreover, this new account must compete for parsimony with the hypothesis that young and older adults adopt different communicative goals when speaking (James et al., 1998). Under this Pragmatic Change hypothesis, older adults adopt the goal in autobiographical contexts of emphasizing the significance of their life experiences rather than the usual goal of imparting information concisely. This assumed age-related change in communicative goals explains both the more favorable evaluative ratings and the topic-specificity of off-topic speech of older adults, and the Pragmatic Change hypothesis provides a simpler and more coherent account of age differences in off-topic speech than cognitive impairment accounts.

In sum, one of the challenges for future generations of information-universal theories is to explain why some language functions decline in old age but not others. As Salthouse (1996; this volume) suggested, specific, local mechanisms, in addition to a general mechanism, may underlie the pattern of spared and impaired abilities in old age.

Information-specific Theories

As a class, information-specific theories deal well with asymmetries in aging effects. However, some information-specific theories originated as descriptions of just such effects. For

example, *Region-Specific Neural Aging* hypotheses link the amount of age-related neurobiological change in specific areas of the brain to patterns of spared and impaired cognitive functions (e.g., Madden & Hoffman, 1997; Moscovitch & Winocur, 1992; Raz, Torres, Spencer & Acker, 1993; West, 1996). Although most Region-Specific Neural Aging hypotheses have focused on memory rather than language functions, the hypothesis that age-related increases in verbosity are linked to age-related, frontal lobe decrements (Arbuckle & Gold, 1993; West, 1996) is an exception.

The *Transmission Deficit* hypothesis is more general in nature, e.g., providing an account of age-linked slowing data (see MacKay & Burke, 1990), and represents a quite different approach to developing an information-specific theory. Under the Transmission Deficit hypothesis, language perception and production depend on the how fast and how much priming can be transmitted across the connections linking representational units, called nodes, in the language-memory system. Priming is a form of subthreshold excitation that prepares a node for activation, the basis for retrieving the information represented by the node (MacKay, 1982, 1987). Because a node is selected for activation only if its priming level reaches a critical difference above that of other nodes in the same domain, the rate and amount of priming transmitted across connections between nodes is an important determinant of what information in memory becomes available. The rate of priming transmission depends on the strength of connections among nodes: Connections become stronger with use (activation), and especially recent use, and weaken over time as a result of disuse. Aging is also postulated to weaken connection strength. Transmission deficits result when relevant connections become especially weak, but the functional effect of transmission deficits depends on the processes and architectures of specific memory systems in Node Structure Theory (NST) which provides the framework for the Transmission Deficit hypothesis. This property enables the theory to account

in a noncircular manner for the asymmetric effects of aging on language comprehension versus production (e.g., Burke et al., 1991; MacKay & Abrams, 1996, in press; MacKay & Burke, 1990). By the same token, understanding this account requires a detailed look at the processes and architecture underlying language-memory systems in NST.

Like other current interactive activation models of language (e.g., Dell, 1986; Dell, Burger & Svec, 1997; Levelt et al., 1991), NST postulates a vast network of interconnected 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. The hierarchical organization of nodes in NST clarifies differences between processes underlying the production versus comprehension of words (MacKay, 1987). By way of illustration, consider the specific nodes in semantic, phonological and orthographic systems in Figure 8.1 for comprehending and producing a familiar word such as star. In comprehension, hearing or reading star transmits bottom-up priming via many orthographic and/or phonological nodes whose connections all converge onto a single lexical node (see Figure 8.1). This convergence enables activation of the lexical node, which transmits priming to interconnected semantic nodes whose activation constitutes retrieval of word meaning. The converging characteristic of bottom-up connections for perception, for example, from phonological nodes to a lexical node, can offset a transmission deficit in any one connection. Moreover, transmission of priming within the semantic system is likewise aided by the many connections that link related concepts and produce convergent or summating priming at semantic nodes (Laver & Burke, 1993). For example, although omitted from Figure 8.1, many semantic propositions linked to star also link to each other (a theoretical definition of semantic similarity or overlap). A higher level propositional node representing the

information that celestial bodies are a topic in astronomy would link celestial bodies to astronomy (a "semantically similar" concept). Priming from astronomy to celestial bodies could therefore offset a deficit in transmission of priming from star to celestial bodies More generally, the interconnected nature of semantic representations will offset a transmission deficit in any one connection within the semantic system.

In production, the idea or picture of a star, for example, activates semantic nodes which transmit priming top-down to the lexical node for star, and activating this lexical node transmits top-down priming simultaneously and divergingly to many phonological nodes (see Figure 8.1). Retrieval of a word's phonology is complete only when nodes at the lowest level (i.e., phonological features) have been primed and then activated. These top-down connections for producing phonology are always one-to-one and this diverging characteristic of top-down connections increases their vulnerability to transmission deficits. Each phonological node must receive sufficient priming from its single top-down connection in order to become activated, without augmentated priming from other phonological nodes which lack the interconnections of semantic nodes: A transmission deficit in a single top-down connection will prevent activation of that node. However, the converging characteristic of bottom-up connections for perception can offset a 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 a transmission deficit in any one connection. The asymmetry in the structure of bottom-up and top-down processes in NST means that the Transmission Deficit hypothesis predicts small or no aging effects for language comprehension tasks, but large age-linked deficits for production tasks, including word retrieval and the production of spelling.

Semantic priming effects further illustrate how the structure of connections within a memory system determines whether age-linked transmission deficits become manifest in behavior. For example, the lexical nodes for star and planet are indirectly connected via shared semantic proposition nodes, for example, is a celestial body, studied in astronomy. Because of these shared links, activating the concept star in the semantic priming paradigm will prime the concept planet, enabling faster lexical decision times for this semantically related word. Why are there no age-related declines in semantic priming effects? First, under NST, priming summates over the multiple connections between highly related concepts like star and planet, and summation of priming reduces the effect of a transmission deficit in any single connection. Second, semantically related concepts such as star and planet are likely to have more indirect links for older than young adults because over the course of their (longer) lifetimes, older adults have acquired more general knowledge in the form of propositions such as, say, stars and planets seem to move with the seasons, and stars affect the temperature of planets. As a result of this enriched semantic network, more connections will link semantically related concepts in the memory systems of older than young adults. Priming will therefore converge across these additional, parallel connections and summate to a greater extent for older than young adults. As a result, semantic priming effects will be at least as large for older adults relative to young adults (see Laver & Burke, 1993).

Summary

All of the theories reviewed above are in the early stages of development. All can explain some aspects of available data on language performance and aging, 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 language comprehension but not language production. Such differential aging patterns come built into Information-specific theories such as the Transmission Deficit hypothesis, but it is too soon to tell how this theory will fare with direct empirical tests.

In the next sections, we describe in greater detail the Transmission Deficit account of age deficits in language production. According to this theory, production deficits occur when nodes that represent information essential to production fail to activate because of weak connections that impair transmission of priming. Such transmission deficits are due to aging, frequency and recency of use, but whether or not they become manifest depends on the architecture of connections within phonological and orthographic systems. We demonstrate how this account applies to age differences in three domains of language production: the tip of the tongue experience, proper name retrieval, and spelling or orthographic retrieval.

Transmission Deficits and Tip of the Tongue States

The TOT experience represents a pure phonological retrieval deficit. Because of this, it has provided an important source of information for developing models of speech production, for example, by indicating that retrieval of lexical and semantic information precedes retrieval of phonological information in speech production (e.g., Burke et al., 1991, Dell, 1986, MacKay, 1987; Levelt, 1989; Miozzo & Caramazza, 1997). TOTs are equally important for developing models of cognitive aging, for example, by indicating age deficits in phonological but not semantic retrieval processes.

The Transmission Deficit hypothesis postulates that TOTs reflect a deficit in the transmission of priming to phonological nodes representing the target word (Burke et al., 1991;

MacKay & Burke, 1990; Rastle & Burke, 1996). A TOT occurs when a lexical node becomes activated via top-down priming, giving access to semantic information about the target word, but some of its phonological information remains inaccessible because transmission deficits weaken connections to its phonological nodes, preventing activation. Rarely and not recently activated nodes have weakened connections, explaining why TOT targets tend to be low frequency words that have not been recently used or encountered (Burke et al., 1991; Cohen & Faulkner, 1986; Harley & Brown, 1998; Rastle & Burke, 1996; see Brown, 1991, for a review). Why are phonological nodes more susceptible to Transmission Deficits than semantic or lexical nodes? In general, phonological nodes are hierarchically linked 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.

The Transmission Deficit hypothesis also explains why partial phonological information and related alternate words come to mind during the majority of TOT experiences (Brown, 1991). Only some of the phonological nodes for producing the target word may be suffering a transmission deficit due to aging or infrequent and non-recent use of the target word. Some subset of the remaining phonological nodes may in fact become activated, providing a basis for partial phonological recall. Persistent alternates also arise when some (but not all) phonological nodes suffer transmission deficits. For example, in a study of naturally occurring TOTs, the persistent alternate charity was repeatedly retrieved instead of the TOT target chastity, and under the model, this was because some of the phonological nodes for chastity received sufficient priming for activation (e.g., the initial ch), trnasmitting bottom-up priming to the lexical node for charity (Burke et al., 1991). Priming was sufficient for charity to be selected for activation and awareness because charity was not suffering transmission deficits. Consistent with this, alternate

words tend to share phonology with the TOT targets (Brown & McNeill, 1966; Burke et al., 1991).

The Transmission Deficit hypothesis predicts the finding that older adults experience more TOT states than young adults because aging reduces connection strength, thereby increasing the probability of transmission deficits which, in the phonological system, are likely to cause retrieval failure. Reduced transmission of phonological priming also predicts that older adults will access less phonological information about the target and fewer persistent alternates, as has been repeatedly observed (Burke et al., 1991; Maylor, 1990a; Cohen & Faulkner, 1986).

An alternative account of TOTs is that persistent alternates cause the TOT by "blocking" retrieval of the target word. Despite its popularity, this inhibition hypothesis has little empirical support. Jones (1989; Jones & Langford, 1987; see also Maylor, 1990a) reported that TOTs increased with prior presentation of words phonologically related to the target word, and argued that this increase simulated the blocking effect of persistent alternates. However, Perfect and Hanley (1992) and Meyer and Bock (1992) demonstrated that Jones' effect reflected a failure to counterbalance materials and that prior presentation of phonologically-related words increased correct responding, a finding consistent with the Transmission Deficit account, but not an inhibition account of TOT states (James & Burke, 1998; Meyer & Bock, 1992).

At least one effect of aging on TOTs is also inconsistent with blocking accounts. Age-related inhibitory deficits should reduce the inhibitory effect of an alternate word on the target, so that older adults should suffer *fewer* TOTs than young adults, but the opposite occurs. Perhaps, however, inhibition is unidirectional, occurring only for the irrelevant information that comes to mind during an attempt to retrieve a target word, so that older adults' decreased ability to suppress irrelevant associations or competing words would increase interference with target

retrieval, thereby causing the observed age-linked increase in TOTs (Hartman & Hasher, 1991; Hasher & Zacks, 1988; Zacks & Hasher, 1994). This being the case, however, older adults should report more alternate words that come to mind persistently during a TOT than young adults, but in fact they report fewer alternate words and less partial phonological information (Burke et al., 1991; Cohen & Faulkner, 1986; Maylor, 1990a). Contrary to this Inhibition Deficit account of the age-related increase in TOTs, older adults don't report that their minds teem with alternate words, but that their minds simply go blank (Burke et al., 1991; Cohen & Faulkner, 1986). Nevertheless, the blocking model of TOTs has retained its popularity (Brown, 1991), perhaps a tribute to the power of the subjectively experienced correlation between TOTs and alternate words.

Phonological Priming Effects on TOTs in Young and Older Adults

What is the evidence that TOTs reflect phonological but not semantic deficits? The phenomenology of TOTs is that the meaning and syntactic category of the target word is available, but not the phonological word form (e.g., Brown, 1991). This has been corroborated in the laboratory where, for example, participants report alternate words in the same syntactic category as the target with greater than chance probability (Burke et al., 1991), and speakers of Italian can accurately report the grammatical gender for an unavailable TOT target (Miozzo & Caramazza, 1997). The effectiveness of different types of cues to a TOT word also attests to the availability of semantic information in TOT states: Resolution of TOTs is unaffected by semantic cues such as an alternative photograph of a person but is aided by phonological cues such as the initial letter(s) of the target word (e.g., Brennen, Baguley, Bright & Bruce, 1990), a phonologically related word, or a sound pattern with the same number of "syllabic peaks" and stress pattern as the target (Kozlowski, 1977; Meyer & Bock, 1992).

The Transmission Deficit model makes clear predictions on how to eliminate transmission deficits in the phonological system and thus improve word retrieval, and we tested these predictions in a series of experiments. Under NST, recent activation strengthens the connections among nodes, increasing the amount of priming transmitted across the connections and reducing transmission deficits which cause TOTs. Therefore, prior processing of phonological segments of a word should increase the word's retrievability and decrease the likelihood of suffering a TOT for that word. These priming effects occur implicitly under the model, and do not require awareness of the prime-target relation. In a repetition priming paradigm, Rastle and Burke (1996) manipulated the type of processing involved in a prior processing task with target words that were the answers to subsequent general knowledge questions. Prior processing of target phonemes reduced TOTs and increased correct recall, and additional semantic processing had no effect on this priming effect. This supports the hypothesis that frequency and recency of target processing influence the likelihood of TOTs, and that the retrieval failure occurs at the phonological level, although a lexical level effect can also be expected with full repetition of the target word.

James and Burke (1998) eliminated lexical level effects by presenting words in the prior processing task (rating "pronunciation difficulty") that were phonologically similar, but not identical to the target. When participants first processed five words that were phonologically similar to the target (e.g., eucalyptus, infidelity, and pessimism for the subsequently presented target, euphemism), interspersed among five unrelated words to prevent attempts to use the prime words as cues to the taget in an explicit conscious search, TOTs decreased relative to when all 10 words were phonologically unrelated to the target. These priming effects clearly occurred at a phonological rather than lexical level because primes and targets were always different words.

A second experiment demonstrated effects of processing phonologically related words following occurrence of a TOT. The TOT-inducing questions were presented first, and when participants reported a TOT, they rated pronunciation difficulty of 10 words that were either all unrelated to the target or half unrelated and half phonologically related. Then, when the TOT question was presented again, the probability of a correct answer, i.e., retrieval of the TOT target, increased after processing related compared to unrelated words. These effects occurred without awareness of prime-target relatedness because the participants could not identify which prime words were related to the target and which were not.

These findings suggest a solution to the puzzle of how TOT targets come "spontaneously" to mind in everyday life when a person is no longer actively trying to resolve a TOT: Phonologically similar words occurring inadvertently in the environment (e.g., on TV, radio or in conversation or internal speech) could activate phonological components of the target that were previously unavailable because of transmission deficits. The TOT target then "pops up," a resolution that will be experienced as spontaneous because there is no awareness of the relationship between the prime word and TOT target.

Neither repetition priming nor phonological priming produced larger effects for older than young adults in the just discussed paradigms. This is consistent with the Transmission Deficit hypothesis if the transmission deficits that precipitate TOTs are comparable in severity for young and older adults, except that older adults simply suffer more transmission deficits, yielding more frequent TOTs. Moreover, if older adults tend to have multiple transmission deficits underlying the TOT for a single word, this would explain why older adults report less partial information when in the TOT state.

Interestingly, however, an age by prime condtion interaction emerges with a homophone priming technique (Burke, Austin & Kester, 1998). Spoken homophones, e.g., burr and Burr, share identical phonological nodes but their lexical and semantic representations differ (Burke et al., 1998; Valentine, Moore & Bredart, 1995). Figure 8.2 illustrates aspects of the representation of the proper name and common noun homophone burr. The lexical nodes for burr(common noun) and Burr(proper name) connect to identical phonological nodes, so that production of burr(common noun) should improve retrieval of Burr(proper name). To test this prediction, participants performed two tasks on alternate trials: a sentence completion task where participants completed a phrase with a single word to (e.g., She sells sea shells at the sea ____) and a picture naming task involving famous persons. The name of the person in the picture naming task was either a homophone of the word in the sentence completion task two trials earlier (e.g., [Dinah] Shore following shore) or unrelated to the earlier word (e.g., [Cary] Grant following shore). Overall, older adults produced fewer correct names and more TOTs than young adults in picture naming,. However, there was an age by prime condtion interaction: Prior production of a homophone reduced TOTs and increased correct naming of the picture, but only for older adults. Indeed, the homophone priming condition eliminated age differences in naming and TOTs.

In sum, the Transmission Deficit hypothesis can account for established characteristics of the TOT state, including its increase with age. Considerable evidence also supports the corollary hypothesis that TOTs are pure phonological retrieval deficits. However, additional research is needed to better understand phonological effects of priming on TOTs. Because the relation between phonological priming effects and aging has implications for the nature of age-linked

transmission deficits, identifying the conditions determining whether and when priming effects increase with aging is an important goal for future research.

Transmission Deficits and Retrieval of Proper Names

Several sources of evidence indicate that proper name retrieval is disproportionately impaired in old age: Proper names are more difficult to retrieve than other information about people such as their occupation (Cohen & Burke, 1993; Valentine, Brennen & Bredart, 1996; Young, Hay & Ellis, 1985), especially for older adults (James, 1997). Burke et al. (1991) found that proper names accounted for more than half the TOTs reported in a diary study, and most were names of acquaintances or famous people, rather than, for example, place names or movie titles. Older adults also reported that remembering proper names deteriorates with aging and represents their most disturbing cognitive problem (Cohen & Faulkner, 1984; Lovelace & Twohig, 1990), although these self reports may reflect the greater importance of remembering proper names, or even the absence of synonyms for proper names, rather than a special retrieval problem relative to other words (Maylor, 1997).

The Transmission Deficit hypothesis predicts that retrieval deficits should be more common for proper names than other words, especially for older adults. To illustrate this prediction, compare the representations of Burr(family name) and burr(common noun) in Figure 8.2. Only a single top-down connection links Burr(family name) to the memory representation for a specific person, unlike burr(common noun) which receives many top-down connections from inter-related semantic propositions. The transmission of priming to the lexical node for Burr(family name) depends primarily on that single connection, whereas for burr(common noun) priming can summate over the many connections from related concepts (Burke et al., 1991; Valentine et al., 1996; cf., Burton & Bruce, 1992; Cohen, 1990). Thus one locus of proper name

retrieval deficits is in activating the lexical node for the proper name. Consistent with this hypothesis, Bredart and Valentine (1998) showed that cartoon characters with meaningful proper names (e.g., Grumpy, Scrooge), which receive connections from semantic nodes as well as name-phrase nodes, were correctly named more often and with fewer TOTs than characters with arbitrary proper names (e.g., Aladdin, Peter Pan) which only receive connections from name-phrase nodes. A second locus of proper name retrieval deficits, as for TOTs in general, is the single top-down connections to phonological nodes, which render proper names especially vulnerable to transmission deficits, causing increased proper name TOTs.

Consistent with these predictions, several sources of evidence suggest that older adults are especially impaired in proper name recall. In naming famous faces, correct responses included both first and last names more often for young than older adults (Maylor, 1998) and latencies for older adults were disproportionately slower for naming, but not for semantic decisions concerning occupation or fame (Maylor & Valentine, 1992; but see Maylor,1997). In a task where participants named pictures of famous people, older adults reported more proper name TOTs than young adults (Burke et al., 1998; Maylor,1990b). However, the age-related increase in proper name TOTs in these studies may simply reflect the general age-related increase in TOTs for all types of words: The studies failed to compare young and older adults' TOTs for names versus other types of information.

In the experimental study of Burke et al. (1991), names of famous people were the only class of words with significantly more TOT responses for older adults than young adults. In fact, 33% of older adults' TOTs were for names of famous people, compared to only 20% for young adults, which indicates an age-linked increase in proper name TOTs while controlling for the increased TOTs for older adults across all word types. However, an analysis of TOTs as a

proportion of unrecalled words in Burke et al. indicated an age-linked increase in TOTs for three classes of words: famous people, object nouns, and verbs and adjectives, inconsistent with a specific age-related impairment in proper name retrieval. Thus, the Burke et al. study does not unequivocally demonstrate that TOTs for names are especially frequent in older adults.

Rastle and Burke (1996), however, found disproportionate age-related increases in TOTs for proper names compared to common nouns: Older adults reported more TOTs for common nouns than young adults, but the age difference was twice as large for proper name TOTs. Moreover, the same pattern also emerged in an analysis of TOTs as a proportion of unrecalled words: Older adults experienced more TOTs than young adults for both common and proper nouns, but the age difference in TOTs was twice as large for proper as common names.

Studies comparing age differences in retrieval of proper names versus other types of biographical information about a person have yielded equivocal results. James (1997) tested predictions of the Transmission Deficit model for age differences in TOTs for proper names versus other words. Participants saw pictures of famous people and attempted to write down the full name and specific occupation of people whose faces they found familiar, indicating TOT states for names or occupations. There were no age differences in correct responses for names or occupations. TOTs for occupations were rare for both young and older adults, occurring for only 2% of the pictures for each age group. TOTs for names, however, occurred more frequently for older adults (17% of familiar pictures) than young adults (11% of familiar pictures). These findings are consistent with the prediction that proper names are more susceptible to retrieval failure than other types of biographical information, and especially so for older adults, but TOTs for occupations were at floor in this study, and therefore the results must be interpreted cautiously.

Maylor (1997) recently argued that age differences in correct recall of proper names versus semantic information about a person indicate that older adults are *not* disproportionately impaired on proper name retrieval. Reanalyzing data from Maylor (1990) on 50-, 60- and 70-year olds, she reported age-related declines in correct recall of semantic information about a familiar famous person and in correct recall of the name of the famous person, given that correct semantic information was recalled. The age difference was *not* statistically greater for names than semantic information, and although numerically the age difference for names was twice as large as for semantic information, this may reflect ceiling effects in recall of semantic information. In a task requiring identification of famous people from their voices, Maylor (1997) eliminated ceiling effects and reported equivalent differences between participants in their 50's and 60's and participants in their 70's and 80's in recall of semantic information and in recall of name.

In sum, proper names are more difficult to recall than other semantic information about a person, but whether older adults show relatively greater deficits for proper names than young adults depends on the measure. Conditional probabilities for recalling proper names versus semantic information reveal no disproportionate decline in proper name retrieval, at least between the ages of 50 and 85 years. TOTs, however, show larger age differences for proper names than other types of words. Clearly, more research is needed on this issue.

Transmission Deficits and Orthographic Knowledge

Two contrasting classes of theories have been developed to explain how young adults map orthography onto phonology, allowing them to pronounce a word they read (and by extension, to spell a word they hear). One class, known as parallel distributed processing (PDP) theories, represents orthographic knowledge in terms of connection strengths or weights within a complex, highly interactive network involving large numbers of excitatory and inhibitory

connections for each word, without rules of any kind for representing either regularly- or irregularly-spelled words (see e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996). The second class of theories, known as "dual route" theories postulate two routes from orthography to pronunciation (e.g., Coltheart, Curtis, Atkins & Haller, 1993). One is an indirect route from orthography-to-phonology-to-semantics-to-pronunciation that incorporates grapheme-to-phoneme correspondence rules. These rules are categorical in nature and translate orthography into phonology for regularly-spelled words, i.e., words whose speech sounds follow the most common orthography-to-pronunciation pattern in the lexicon, for example, bunt, punt, and hunt. The second route leads directly from orthography to semantics, bypassing phonology on the input side. This "direct route" makes no use of rules of any kind, and translates orthography into phonology for irregularly-spelled words, i.e., words that contain one or more speech sounds that follow a unique or uncommon orthography-to-pronunciation pattern. For example, bush and push are irregularly-spelled because the [U] in these words is pronounced in an uncommon way.

The NST and Transmission Deficit hypothesis represent a hybrid PDP-dual route theory for perceiving and producing orthographic information. As with bottom-up processes for speech perception, perceiving orthography differs in fundamental ways from the top-down processes for producing orthography and these differences give rise to age-linked asymmetries between perception versus production. Like phonological nodes, orthographic nodes are part of a hierarchically organized network: Letter nodes in the orthographic system are connected laterally to phonological nodes, relating spellings to their most common sounds, an indirect route that can be used for regularly spelled components of words (MacKay & Abrams, in press). Figure 8.1 shows these lateral connections for the regularly spelled word star.

Unlike dual route theories, NST focuses on speech sounds and letters rather than words as unit of analysis in defining "regular spelling": A speech sound in a word is regularly-spelled if it follows the most common spelling pattern for that speech sound in the lexicon, but is irregularly-spelled if it follows a unique or uncommon spelling pattern. For example, the speech sounds /ɚ/ in cooker is regularly-spelled because most words, e.g., worker, baker, amber, follow the same spelling pattern, but /ɚ/ is irregularly-spelled in the word burr because /ɚ/ is spelled [UR] in only a few words, e.g., fur, duration. The double [r] in burr is also irregular because most words, e.g., fur, duration, spell /r/ with a single [r].

Lateral connections in NST suffice to correctly spell the regularly-spelled aspects of an irregularly-spelled word, but to spell the irregularly-spelled aspects, a "quasi-irregular node" must be activated to introduce the irregularly-spelled letters and to prevent intrusion of the regular spelling pattern. Figure 8.2 shows the quasi-irregular nodes and lateral connections for spelling the word burr in the orthographic system of NST (omitting nodes within the muscle movement systems for handwriting and typing). The lexical nodes representing burr (both common noun and proper noun) are connected top-down to a node in the orthographic system that represents the fact that burr spells /ə/ as [U]. This quasi-irregular node is connected top-down via an inhibitory connection (represented by a broken line) to the letter [E], the usual spelling, and via an excitatory connection to the letter [U]. As a result, activating this quasi-irregular node inhibits the letter [E] to counteract the lateral connections for regular spelling, and enables activation of the letter [U] to correctly spell /ə/ as [U]. This same quasi-irregular node also becomes activated when spelling, writing, or typing the small number of other words that spell /ə/ as [U], ergo the term quasi-irregular. The lexical nodes representing burr are connected to a second quasi-irregular node that represents the fact that burr spells /r/ irregularly as [RR]. This quasi-irregular node

blocks (represented by the broken line) the self inhibition (represented by the loop) that follows activation of the node for R (see MacKay, 1987), allowing R to be doubled.

Aging and Retrieval of Orthographic Knowledge

We now examine theoretical effects of age-linked transmission deficits on orthographic retrieval in NST. Older adults will be especially likely to misspell irregularly-spelled English words because nodes critical to the correct spelling depend on a single connection within the network. For example, in spelling burr, the activated lexical node can only contribute top-down priming to the quasi-irregular nodes in Figure 8.2 via a single connection. Consequently, deficits in transmission of priming across that one connection to each quasi-irregular node will reduce the likelihood of activation. One possible consequence of a transmission deficit is that the wrong quasi-irregular node becomes activated: Because only the most-primed quasi-irregular node can be activated at any point in time, the wrong quasi-irregular node may be activated in error if a transmission deficit prevents the appropriate quasi-irregular node from achieving most-primed status. In short, the Transmission Deficit hypothesis predicts that older adults will sometimes misspell irregularly-spelled words by applying the quasi-irregular pattern for some other irregularly-spelled word.

A second possible consequence of transmission deficits is that no quasi-irregular node achieves sufficient priming to become activated, so that the regular spelling pattern predominates. For example, if the quasi-irregular nodes are not activated in spelling the word burr, the letter [E] will not be inhibited, the letter [U] will not be activated, and the [r] will not be doubled, so that burr will be misspelled ber, following the pattern represented by the lateral connections for spelling this phoneme in most English words (see Figure 8.2). In short, the Transmission Deficit hypothesis predicts that older adults will misspell irregularly-spelled words as regularly-spelled.

Misspellings due to age-linked transmission deficits are much less likely for the regularly- than irregularly-spelled aspects of words under NST. The lateral, phonology-to-orthography connections for spelling regularly-spelled letters are used with extremely high frequency over the course of a lifetime, a factor that will offset transmission deficits. By comparison, irregularly-spelled components receive relatively little practice because they occur in only a few irregularly-spelled words, and even irregularly-spelled words generally contain more regularly- than irregularly-spelled components. Thus, the lateral connection for spelling /b/ as [B] may be activated many times a day when typing, writing or spelling the many regularly-spelled English words that contain /b/, and the many irregularly-spelled words that contain one or more regularly-spelled /b/s. By contrast, the single connections linking burr to each of its quasi-irregular nodes are unique to the word burr (see Figure 8.2), and only transmit priming when writing, typing, or spelling the word burr. Similarly, the single connection linking a quasi-irregular node to a letter, say, [U], is only activated when writing, typing, or spelling the small number of words that spell /ə/ as [U], e.g., fur. The frequency difference between regularly- versus irregularly-spelled letters predicts that older adults will exhibit a greater deficit in spelling irregularly- than regularly-spelled letters. Nonetheless, the lateral connections that link phonological nodes to the orthographic nodes for representing regular spelling constitute a single source of priming that should ultimately succumb to age-linked transmission deficits under the Transmission Deficit hypothesis, so that very old adults will eventually exhibit a deficit in spelling regularly- as well as irregularly-spelled aspects of words.

NST also predicts that aging will have disproportionately greater effects on production of orthographic patterns than on perception of orthographic patterns. The reason is that bottom-up priming converges in a way that offsets age-linked transmission deficits, so that aging will impair

production of orthographic patterns more so than perception. Theories that do not postulate fundamental differences between perception and production processes, such as information universal theories, and attribute cognitive aging to a single factor, e.g., general slowing, do not make this asymmetric prediction, and can only explain age-linked asymmetries between perception versus production in terms of experimental artifact, e.g., differences in stimuli, participant characteristics, or difficulty of the perception versus production tasks (see Salthouse, this volume)

MacKay et al. (in press) developed a paradigm for comparing the perception versus production of spelling patterns, and their results provide clear and dramatic support for the age-linked asymmetry prediction of NST. Young and older adults with normal or corrected-to-normal vision saw on a computer monitor briefly presented words that they knew would be either correctly-spelled or deliberately misspelled (in unspecified ways). The misspellings were created by adding or substituting a single letter in a word, e.g., endeavor misspelled as endeavuor. Participants had two tasks. The first was a perception task: to respond "right" to indicate correct spelling or "wrong" to indicate incorrect spelling. The second, immediately subsequent task involved production: Participants wrote out the spelling of the word, exactly as presented on the screen.

Results of the perception task indicated that recognizing spelling patterns did not decline with age for either correctly or incorrectly spelled words (see Figure 8.3, left panel). That is, perception of spelling patterns remained constant in old age, consistent with the frequently observed small or nonexistent age effects for other aspects of language perception discussed earlier. However, age declines did occur in the production task. Older adults correctly reproduced the incorrectly spelled words significantly less often than young adults ($p = .02$), even when both

groups indicated awareness that these stimuli were misspelled (see Figure 3, right panel). Older adults also correctly reproduced correctly spelled words significantly less often than young adults ($p = .02$), even when the words had high frequency of use, and even when they had indicated awareness in the immediately prior perception task that the stimuli were correctly spelled (see Figure 8.3, right panel). These age-related declines in spelling production cannot be explained in terms of "memory load" and indicate that information about the orthography of words becomes more difficult to retrieve with age, consistent with the NST prediction and with declines discussed earlier for retrieval of phonology in spoken language production.

MacKay et al. (in press) also showed that the age-linked asymmetries in Figure 8.3 were specific to the task factor (perception versus production) rather than general in nature: Not every factor that affects the detection and retrieval of misspellings exhibits the same interaction with either age or task. Specifically, letter repetition strongly influenced the detection and retrieval of misspellings for both young and older adults: Repeated-letter misspellings, e.g., elderdly, were harder to detect, and if detected, were harder to recall than unrepeated-letter misspellings e.g., elderkly. However, these "repetition deficits" did not exhibit age-linked asymmetries: Effects of repetition were symmetric or equivalent in magnitude for young and older adults in both the detection and retrieval tasks.

MacKay and Abrams (in press) examined aging effects on correct spelling of auditorily presented words. NST predicts that both young and older adults will misspell auditorily presented low frequency words more often than high frequency words because word frequency covaries with recency and frequency of node activation, two factors that offset transmission deficits (see e.g., Burke et al., 1991). A related prediction is that errors will tend to involve irregularly-spelled letters more often than regularly-spelled letters for both high and low

frequency words, due to the greater frequency of regularly- than irregularly-spelled components. The third prediction concerns two types of misspellings: same-pronunciation errors versus different-pronunciation errors. Same-pronunciation errors are pronounceable in the same way as the original, correctly-spelled word because they follow the phonology-to-orthography pattern found in the majority of English words. For example, 97% of English words spell /i/ as [I], and only 3% spell /i/ as [Y] as in cyst (Barry, 1994), so that cist is a same-pronunciation misspelling of cyst. By contrast, different-pronunciation errors cannot be pronounced in the same way as the correctly-spelled word because their phonology-to-orthography pattern is unique or found in few other English words, e.g., sausage misspelled as sasuage. Under NST, same-pronunciation errors will be more common than different-pronunciation errors for both irregularly- and regularly-spelled letters in misspelled words because same-pronunciation links have greater frequency than different-pronunciation links.

MacKay and Abrams (in press) presented a tape recorded series of "difficult-to-spell" English words to young (age 17-23 years), older (age 60-71 years), and very old participants (age 73-88 years). Half the words were relatively common in English, e.g., rhythm, spontaneous, and half were relatively rare, e.g., chauffeur, pageant. The participants' task was to write each word down at their own pace during a 20 sec interval between words. The instructions encouraged accurate spelling and de-emphasized response speed. To rule out explanations based on age-linked sensory or perceptual deficits, perceptual errors (where a word was mispelled as some other phonologically similar word) were excluded from all analyses reported here.

The results replicated the age-related decline in correct spelling in MacKay et al. (in press) with several refinements: Misspellings increased with age, especially for high-frequency words, and this pattern of age differences remained when differences in vocabulary were factored

out in covariate analyses shown in Figure 8.4 (left ordinate). Low frequency words were correctly spelled less often than high frequency words, and correct spelling decreased with aging for both high and low frequency words, consistent with NST predictions (see Figure 8.4). However, the relatively greater age difference for high- than low-frequency words was not consistent with NST, but almost certainly arose because the young adults were unfamiliar with many of the low frequency words. Consistent with this hypothesis, same-pronunciation errors on the low frequency, irregularly-spelled words were especially common for young adults (see Figure 8.4, right ordinate) as if they had reverted to "spelling by sound," a default strategy for spelling unknown words.

Also apparent in Figure 8.4 (right panel), is the finding that the older and oldest adults made more different-pronunciation errors, e.g., calendor, than young adults in spelling both high and low frequency words, and the older and oldest adults made more same-pronunciation errors, e.g., calender, than young adults in spelling high frequency words, both findings consistent with NST.

The age-linked decline in spelling ability was not due to a general slowing factor, even one embedded within a connectionist architecture resembling NST, because the words were spoken slowly, participants were instructed to stop and restart the tape recorder if they needed more time, and they wrote down the words at their own pace, with response speed de-emphasized in the instructions. Even the sophisticated "processing-speed theory" of Salthouse (1996) seems incapable of explaining the data. In processing-speed theory, general slowing degrades cognitive performance because the products of earlier processing are no longer available at the time when later processing requires those products (the simultaneity mechanism). However, decaying processing products are difficult to imagine in this task: Written spelling retrieval runs off rapidly

letter by letter from left to right in a word, and products of earlier processing are available on the page.

Nor can the age-linked decline in spelling ability be explained by embedding an Inhibition Deficit hypothesis within the cognitive architecture of NST. If inhibitory but not excitatory connections exhibit age-linked impairment (e.g., Hasher & Zacks, 1988; Zacks & Hasher, 1994), then failure of an inhibitory link (see Figure 8.2) might cause an age-linked increase in same-pronunciation errors, but not also an age-linked increase in different-pronunciation errors, contrary to present data. The similarities between age-linked declines in orthographic and phonological retrieval (reviewed earlier) are also difficult to explain under an Inhibition Deficit hypothesis.

More refined analyses in MacKay and Abrams (in press) that used letters rather than words as the dependent measure indicated that the older and oldest adults were especially likely to misspell irregularly-spelled letters relative to young adults, with no age-linked difference in the probability of misspelling regularly-spelled letters. However, the very oldest adults exhibited deficits in spelling regularly-spelled letters, consistent with the NST claim that even the frequently used lateral connections representing regular spelling constitute a single source of priming that eventually succumbs to age-linked transmission deficits. That is, regularly-spelled letters involve a one-to-one lateral connection in NST (see Figure 8.1 and 8.2), and one-to-one connections are especially susceptible to age-linked transmission deficits, but because these lateral phonology-to-orthography connections receive so much use, effects of transmission deficits in these extremely strong connections only became evident in the oldest adults.

Another letter-level finding was that the oldest adults produced more same-pronunciation misspellings than did young adults for irregularly-spelled letters, consistent with the NST

prediction that the most likely outcome of transmission deficits in connections to or from quasi-irregular nodes is a same-pronunciation misspelling. The oldest adults also made more different-pronunciation errors than the young and older adults when spelling regularly-spelled letters, but these misspellings involve an additional process under NST, namely inappropriate activation of a quasi-irregular node. That is, for the oldest adults, transmission deficits may have reduced priming delivered to the appropriate nodes, so that an inappropriate quasi-irregular node received more priming and became activated, giving rise to these different-pronunciation errors.

Conclusions

Experimental evidence accumulated over the last 20 years strongly supports a general asymmetry in the effects of aging on language perception versus production. Older adults exhibit clear deficits in retrieval of phonology and orthography, with no corresponding deficits in language perception and comprehension, independent of sensory and new learning deficits. This emerging pattern presents a fundamental challenge for theories of cognitive aging, which must explain why some aspects of the language memory system are so much more vulnerable to effects of aging than others. A decremental approach to theory construction that addresses only the deficits in cognitive aging and leaves unspecified the mechanisms underlying preserved cognitive functions is no longer a viable option.

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Footnote

1. In particular, older adults more so than young adults misspelled irregularly-spelled letter combinations by regularizing them, e.g., calendar = > calender, and only the oldest older adults (over age 73) misspelled regularly-spelled combinations more often than young adults, e.g., calendar = > kalendar.

Figure Captions

Figure 8.1. Example memory representation of semantic, phonological and orthographic information linked to the word star. Some semantic connections between star and planet are shown. Many nodes necessary for perceiving or producing these words have been omitted to simplify the figure.

Figure 8.2. A sample of nodes and connections in the semantic, phonological and orthographic systems representing the proper name Burr and its homophone, the common noun burr. Broken top-down links indicate inhibitory connections, and solid top-down links indicate excitatory connections (see text for explanation).

Figure 8.3. Probability of correct detection (left panel) for young and older adults, and conditional probability of correct retrieval given correct perception (right panel) for correctly-spelled and misspelled stimuli (from MacKay et al., in press).

Figure 8.4. Mean percent correct spelling per participant (adjusted with Nelson-Denny scores as covariate; left ordinate), and mean number of same-pronunciation and different-pronunciation errors per participant (adjusted with Nelson-Denny scores as a covariate; right ordinate) for young, older, and oldest adults spelling high and low frequency words (N=40) (from MacKay & Abrams, in press).