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Towards a Model of Language Attrition: Neurobiological and Psychological Contributions

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Research in L2 attrition is a relatively new enterprise which is in need of a comprehensive theory/model. This paper presents a tentative cognitive-psychological model of language attrition, which draws on information from studies in L2 attrition, neurobiology, and psychology. This is to demonstrate that a model based on consideration of the brain has the potential of providing a plausible account of the process of language attrition, as well as the process of language acquisition.

INTRODUCTION

Language attrition refers to "the loss of any language or any portion of language by an individual or a speech community" (Lambert & Freed, 1982, p. 1). Four types of language attrition are generally recognized: first language (L1) loss, second or foreign language (L2/FL) loss[1], death of an entire language, and language deterioration in neurologically impaired patients or the elderly. The focus of the present paper will be on L2 attrition.

Although L2 attrition has recently gained attention, the number of studies is still limited, and there is a need for a theory or model of L2 attrition. The few theories or models now available offer only descriptions or abstract characterizations of linguistic behavior (e.g., "generalization," "simplification," etc.). These, however, are merely useful metaphors which, by themselves, do not provide an account of why such behaviors take place (Churchland, 1986; Schumann, 1990a). A model of the mind/brain should incorporate neurobiological reality in order to provide a more plausible explanation of the process of language acquisition and

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attrition (Jacobs & Schumann, 1992). Thus, an attempt is made here to demonstrate that neurobiology has significant bearing on the formation of a model of language attrition.

The present paper (1) summarizes key findings in L2 attrition research[2], (2) examines the neurobiological basis for language attrition, and (3) provides a tentative model of language attrition. The summary illustrates what must be accounted for in a model of language attrition. Neurobiology provides a means to account for language attrition. The tentative model is a result of integrating findings from studies in L2 attrition, neurobiology, and psychology.

SECOND LANGUAGE ATTRITION RESEARCH

Summary of findings in L2 attrition studies

In sum, a model/theory of language attrition must be able to account for, as least be compatible with, the following characteristics observed in language attrition data:

(1) loss in reverse order of acquisition;
(2) inverse relationship between loss and language proficiency;
(3) critical threshold of knowledge beyond which loss is less likely;
(4) residual learning in the beginning of the incubation period;
(5) initial plateau before attrition sets in;
(6) permastore content and the retention of frequent and/or pragmatically laden expressions, regardless of lack of input and use;
(7) attrition as a gradual process from less accessibility to complete loss;
(8) critical period of language attrition around the age of 8 or 9;
(9) the amount of L2 use rather than length of exposure as determining language proficiency and degree/rate of loss;
(10) affect as an indirect determinant of language use and attrition.

The following sections provide some elaborations of these characteristics.

The Reverse Order Hypothesis: Last Learned, First Forgotten

The process of forgetting a language is often believed to be the undoing of the learning process. The notion has been interpreted to refer to two related but different characteristics of language loss: the "reverse order hypothesis" and the "inverse relation hypothesis." The reverse order hypothesis, which comes from the notion of "regression" in aphasia. (Jacobson, 1962), states that attrition is the mirror image of acquisition, that is, the last thing learned is the first to be forgotten. The hypothesis may refer to three different linguistic levels (De Bot & Weltens, 1991): (i) within skills--within phonology, morphology, syntax, lexicon, etc. (i.e., intra-skills level); (ii) within languages--in acquisition, perception precedes production, and spoken language precedes written language; in language loss, the sequence is reversed (i.e., intra-linguistic level); and (iii) between languages--with respect to the order of acquisition and loss of languages in multilinguals (i.e., inter-linguistic level).

The reverse order hypothesis at the intra-skills level has been tested and supported cross-linguistically (Cohen, 1975; Berman & Olshtain, 1983, Olshtain, 1986; Hansen, 1980, cited in Weltens, 1987; Moorcroft & Gardner, 1987; Jordens, De Bot & Trapman, 1989; and Olshtain, 1989). These studies investigated the use of specific grammatical structures by L2 learners and generally found that forms learned latest were lost first. The generalizability of reverse order at the intra-level skills level is limited, however, because the hypothesis has been tested only on a limited number of specific syntactic structures.

The reverse order hypothesis at the intra-linguistic level has been tested as well (Kennedy, 1932; Geoghegan, 1950; Scherer, 1957; Smythe, Jutras, Bramwell & Gardner, 1973; Cohen, 1974; Bahrick, 1984a, 1984b; Moorcroft & Gardner, 1987; Weltens, 1987; Van Els & Weltens, 1989; Weltens & Cohen, 1989; Weltens, De Bot & Schils, 1989; Yoshida, 1989; Seya, 1990; Yoshida & Arai, 1990). The majority of these studies assessed language skills before and after a three month summer vacation and analyzed the types and amount of skills lost as a result of the interval. Results are mixed, perhaps because relatively little loss takes place during such a short interval. There are indications of "residual learning" (Cohen, 1975; Scherer, 1957; Weltens et al., 1989), a phenomenon whereby incorrect patterns become "unlearned" (e.g., hypercorrection of a certain form disappears) after L2 use is discontinued. Nevertheless, the reverse order hypothesis at the intra-linguistic level appears to be

generally supported: phonological skills are retained better than lexical and grammatical skills, receptive (i.e., listening, reading) skills better than productive (i.e., speaking, writing) skills, metalinguistic skills better than linguistic skills, listening skills better than reading skills, and semantics/vocabulary better than syntax/grammar. The reverse order hypothesis at the inter-linguistic level, compared with the intra-skills level and the intra-linguistic level, remains largely unexplored.

The Inverse Relation Hypothesis: Better Learned, Better Retained

The inverse relation hypothesis postulates that there is an inverse relationship between proficiency level prior to the onset of attrition and the rate and/or the amount of loss. In other words, what is learned best is least forgotten, and those who have learned better, or become more proficient, are less vulnerable to loss. The hypothesis has been supported by several studies (Godsall-Myers, 1981; Bahrick, 1984a; 1984b; Moorcroft & Gardner, 1987).

The influence of L2 proficiency on the order of loss has been observed in studies which found that beginning students lose more grammar than vocabulary, while advanced students lose more vocabulary than grammar (Moorcroft & Gardner, 1987; Weltens, 1987; Van Els & Weltens, 1989; Weltens & Cohen, 1989; Weltens et al., 1989). Moorcroft and Gardner (1987) attribute this finding to the degree of stability of L2 knowledge. They argue that less proficient learners have a relatively unstable knowledge of grammar and, therefore, are more likely to lose recently learned grammatical structures than vocabulary. In comparison, more proficient learners have a relatively stable knowledge of grammar, which is learned first, and a larger among of lexical knowledge. They are, thus, more apt to lose vocabulary. Observations in L1 loss support such claims, since the lexicon is affected in L1 loss more so than grammar. Presumably, native speakers have a complete mastery of L1 grammar.

The level of L2 stability has been claimed to affect the degree of attrition as well (Olshtain, 1986; De Bot & Clyne, 1989). Neisser (1984) proposes that there is a "critical threshold" of language proficiency level beyond which language skills become less vulnerable to attrition. What Pan and Berko-Gleason (1986) call the "critical mass of language that, once acquired, makes loss unlikely" (p. 204) seems to refer to an identical notion. The notion is in line with studies which report an "initial plateau" or "a period of

a few years during which skills are relatively unaffected before attrition actually sets in" (Weltens & Cohen, 1989, p. 130), especially in the case of high proficiency L2 learners (Weltens & Van Els, 1986; Weltens, 1989; Snow, Padilla, & Campbell, 1984 and Schumans, Van Els, & Weltens, 1985, both cited in Weltens & Cohen, 1989). In other words, a learner who has reached the critical threshold of L2 proficiency is more likely to exhibit some resistance to attrition, especially in the early stages of disuse. It is important to note that the level of proficiency is not necessarily the consequence of length of exposure/training (Kennedy, 1932; Flaughter & Spencer, 1967).

Not all of the studies mentioned above explicitly test the reverse order hypothesis or the inverse relation hypothesis, and scarcely any study has tested both hypotheses together. Nevertheless, the literature taken together seems to imply that the two hypotheses capture the main linguistic characteristics of language attrition. It may be that the two hypotheses refer to separate processes taking place in language attrition, since "what is best learned, whether early or late in the acquisitional history" may "be last lost" (Berko-Gleason, 1980, p. 8 cited in Freed, 1982). In the present study, however, the two processes are viewed to be outcomes of identical biological mechanisms that underlie language acquisition and attrition.

The Effect of L2 Use on Attrition and the Existence of Permastore L2 Knowledge

Although degree of attrition is generally a function of the length of L2 disuse, there are certain linguistic elements that survive loss regardless of lack of practice (Berman & Olshtain, 1983; Bahrick, 1984a; 1984b; Moorcroft & Gardner, 1987; Weltens 1987; Lambert, 1989; Nakazawa, 1989a, Yoshida, 1989; Nakazawa & Yoshitomi, 1990; Seya, 1990; Yoshida & Arai, 1990; De Bot, Gommans, & Rossing, 1991). These elements include listening comprehension, phonology, and metalinguistic skills in general as well as very frequent and/or pragmatic-laden items such as closed class vocabulary, idioms/fixed expressions, and interjections and fillers (e.g., um).

Bahrick (1984a, 1984b) found that while a large portion of Spanish knowledge is lost within a few years after the termination of training, the remainder is immune to further losses for as long as 25 years. Much of that content survives 50 years or more. Bahrick calls this "portion of knowledge with a life span in excess of 25

years" "the permastore content" (1984a, p. 111), and concludes that (1) a large amount of information can survive in the permastore with minimum rehearsals during the interval, (2) the amount of content in permastore is a function of the level of training (i.e., length of training, final course level and grade), and (3) a large proportion of semantic knowledge (especially receptive vocabulary) is retained in permastore-content.

Language Attrition, Aphasia, Dementia, and the Speech of the Elderly

Although a parallel between language attrition and aphasia claimed by Jakobson (1962) has been challenged (Caramazza & Zurif, 1978; De Bot & Weltens, 1991), impressive similarities between language attrition and dementia, and between language attrition and the speech of the elderly have been suggested (Obler, 1982; Obler & Albert, 1989). Linguistic elements which are particularly robust include items, such as function words, certain overlearned sequences/automatic speech, as well as emotion-laden items, proverbs/idioms, and metalinguistic knowledge.[3]

Attrition as Complete Loss Versus Decreased Accessibility

Aside from the retention of certain permastore-content, and following the initial resistance to attrition (i.e., initial plateau, residual learning) in the case of proficient learners, the attrition process exhibits a normal forgetting curve, involving a large loss followed by a more gradual loss (Godsall-Myers, 1981; Yoshida, 1989). Attrition may not necessarily refer to complete loss of skills/items but to difficulty in retrieving them. Evidence of retrieval difficulty is observed in strategies adopted by people suffering language loss, such as "progressive retrieval" of lexical items, where people start with an inappropriate choice of a word and eventually arrive at the correct one (Sharwood-Smith, 1983; Cohen, 1986, 1989; Olshtain, 1989), and circumlocution as a means of avoiding words which have become less accessible (Olshtain & Barzilay, 1991; Turian & Altenberg, 1991). Better performance on recognition tasks than on recall tasks (Bahrick, 1984a, 1984b) also implies that items have not been completely lost from memory.

Critical Period of Language Attrition

Age and cognitive development are very likely to have significant effects on language attrition. The limited number of studies to appear so far imply that children older than 9 years of age suffer less language loss, especially if they have reached a certain stability in L2 knowledge (Berman & Olshtain, 1983; Olshtain, 1986, 1989; Cohen, 1989, 1989; Yoshida, 1989; Yoshida & Arai, 1990).

Berman and Olshtain (1983), Olshtain (1986), and Olshtain (1989) are longitudinal studies which examined the attrition of English as an L2 of Hebrew-speaking returnee children, aged 5 to 14. The younger children, aged 5 to 8 years old, exhibited a reversal process of acquisition in their uses of irregular noun plural forms and verb past forms, while the older children did not (Olshtain, 1989). Olshtain (1986) suggests that the older children's knowledge of irregular forms had reached a level of stability which reduced the possibility of losing them despite the lack of positive feedback. Speaking and writing skills were also lost most significantly with the younger subjects (Berman & Olshtain, 1983).

Studies by Yoshida (1989) and Yoshida and Arai (1990), which investigated the attrition of English as an L2 of Japanese returnee children aged 6 to 15, also imply that age might influence the degree and/or rate of attrition. Although there was a tendency for L2 speaking skills to decline as a function of length of non-use, children over 8 years of age generally outperformed the younger children in terms of vocabulary use, utterance number, length, and complexity, regardless of the length of interval. Better retention of productive vocabulary in oral language by a 13-year-old is reported in Cohen (1989) as well. The younger child of age 9 exhibited greater loss both in the types and tokens of the vocabulary produced during a storytelling task.

Studies in psycholinguistics and neuroscience suggest that there are maturational constraints on language acquisition(Oyama, 1976, 1978; Johnson & Newport, 1989; Long, 1990). From an extensive review of the literature, Long (1990) concludes that there seem to be multiple sensitive periods to language acquisition. The sensitive period for acquisition of native-like phonology ends at about 5 years of age, while the sensitive period for acquisition of native-like syntactic knowledge ends at about 15 years of age. Different rates and degrees of loss found across linguistic levels (i.e., reverse order hypothesis at the intra-linguistic level) may be a consequence of such multiple sensitive periods.

Research on children raised in the wild, deaf children and aphasics also support the notion of maturational constraints. Curtiss (1981), in her study of the literature on isolated children, observed that children whose approximate age at discovery was over 8-10 years, developed little or no language (i.e., syntax and function word vocabulary). studies on the acquisition of American Sign Language suggest that there is a critical period for acquiring the morphological system of sign language, which may end as early as 7 years of age (Newport & Meier, 1985; Newport & Supalla, 1990). Moreover, Curtiss (personal communication) suggests that the critical period for language acquisition may be earlier than puberty, around 8 to 10 years of age. Taken together, studies cited in this section indicate the possibility of a common critical period for language (especially productive syntactic skills), generally occurring by the end of the first decade of life.

Affect and L2 attrition

Gardner and his colleagues maintain that the use of L2 during the incubation period (i.e., the period between the termination of language training and the time when retention is assessed) is crucial for retention, and that motivation plays a mediating role to enhance both the initial language acquisition and the use of L2 during the incubation period (Gardner, 1982; 1985; Gardner, Lalonde, Moorcroft & Evers, 1985; Gardner, Lalonde & MacPherson, 1987; and Gardner & Lysynchuk, 1990). Other studies also stress the effect of language use (Edwards, 1976; 1977) and motivation (Nakazawa, 1989) on the degree of L2 loss. Social-psychological variables, which are crucial to the acculturation model in SLA (Schumann, 1978), are argued to be some of the main determinants of language loss as well (Olshtain, 1989; Olshtain & Barzilay, 1991).

It is interesting to note that items with great pragmatic load (i.e., "the extent to which the feature normally convey[s] extra-linguistic information such as affect or important status relationships") (Lambert, 1989, p. 8), including idiomatic expressions and social fillers, are less likely to be lost once they are learned (Berman & Olshtain, 1983; Lambert, 1989; Yoshida, 1990; De Bot & Weltens, 1991). Schatz (1989) proposes that such items signal the L2 learner's assimilation to the target culture. They may also be regarded as expressions that help the learners maintain real-life, social-communicative interaction.

NEUROBIOLOGICAL SUPPORT OF LANGUAGE ATTRITION PHENOMENA

Neural Plasticity as the Mechanism of Learning and Forgetting

The neurobiological basis of learning and memory is claimed to be a consequence of neural plasticity, the adaptive capacity characteristic of biological organisms (Squire, 1985). An organism "can modify its nervous system" and "later behave differently as a consequence of these modifications" (p. 295).

It has long been known that animals raised in enriched, complex environments perform better on various behavioral tasks than those raised in non-enriched, simple environments, Such differences in behavioral performance seem to result from neurobiological alterations (e.g., changes in gross morphology, brain weight, cortical histology, neurophysiology, neurochemistry, and dendritic branching) induced by environmental factors (Diamond, 1988; Jacobs, 1991; Jacobs & Schumann, 1992; Jacobs & Scheibel, In Press).

Studies on the effect of an enriched environment are gradually being extended to humans. Dendritic branching analyses, which are claimed to reveal the cortical consequences of formal learning (Holloway, 1966), have indicated that the quantity of dendrites in the gray substance of the human brain and spinal cord (i.e., dendritic neuropil) is a possible function of education level and/or predominant lifetime experiences such as occupation (Scheibel, Conrad, Perdue, Tomiyasu & Wechsler, 1990; Jacobs, 1991; Jacobs, Schall & Scheibel, In Press). Idiosyncrasies found in cortical topographical representations are largely dependent on anatomical changes reflecting individual experience (Merzenich, Recanzone, Jenkins & Grajski, 1990).

Recent advances indicate that information is contained in connections between neurons (i.e., nerve cells), and that use-dependent anatomical change in such connections is a possible substrate for enduring increases in synaptic connectivity essential for memory storage (Squire, 1985). Neuronal connectivity involves dynamic processes such as cooperation, competition, and reorganization among neural elements. The formation and modification of connectivity occur throughout life. The wiring of the brain is only roughly aligned prenatally, during which the target of synaptic connections is defined genetically. The process of fine

tuning continues well after birth, but becomes dependent on the specific interactions between the organism and its environment (Kandel & Jessell, 1991). Increases is synaptic strength in the mature nervous system are typically accompanied by decreases in the strength of competing connections (e.g., competitive changes in axons occurring in the representation of the hand in adult sensorimotor cortex due to experience-based variables) (Purves & Lichtman, 1980; Wiesel, 1982; Jenkins & Merzenich, 1984; Squire, 1986). There are biological constraints, however, which limit the effects of environmental factors. Thus the process is both experience-based, genetic and epigenetic (Jacobs, 1988; Kupfermann, 1991a).

Memory Consolidation and Different Sites of Memory

Reorganization of connections that result from neuronal plasticity involves time. The idea that changes in memory storage occur across time was proposed by Burnham (1903) , and is commonly referred to as "memory consolidation" (Squire, 1985). Squire (1985) proposes that there may be two subtypes of long-term memory: "intermediate memory," which is relatively sensitive to disruption, and a relatively permanent memory. According to Squire (1985), intermediate memory may be stored in the lateral part of the brain close to the midline (i.e., medial temporal lobe), whereas permanent memory may be memory transformed into the cortex on the external surface of the brain (i.e., neocortex).

Recent studies in neurobiology indicate that memory of stimuli is stored as changes in the same neural systems which participate in the stimuli's perception, analysis, and processing (Squire, 1986). In other words, the processing site of certain information becomes the memory storage site of that information, at least temporarily. This claim is based on data from patients with brain lesions. Lesions resulting in the loss of previously acquired information also impair the ability to re-acquire the same information. In complex processing, the respective information is assembled further by other higher-order systems (e.g., associative areas), resulting in the participation of a large amount of tissue without any redundancy or reduplication of function across levels. The distribution of memory storage sites will depend on the nature (e.g., complexity) of the information to be learned (Squire, 1985).

For example, in visual perception and memory, information about form is conveyed through different visual pathways from those that convey information about color. The cells in different

visual pathways show different selectivities and respond only to certain visual stimulus parameters, such as shape, form, size, and direction of movement (Kandel, 1991). Information about particular features of the stimulus converges in a higher-level visual processing region of the cortex (i.e., the inferior temporal cortex) that is thought to integrate such individual information into one representation (Squire, 1985). Thus, the storage of temporary information may occur in each cortical processing system, which is later associated at a different cortical region responsible for higher-level (e.g., cognitive) functions. It is now believed that such parallel processing and modular organization is present in all sensory cortices (Mason & Kandel, 1991). Memory, therefore, "is localized in the sense that particular brain systems represent specific aspects of each event, and it is distributed in the sense that many neural systems participate in representing a whole event" (Squire, 1986, p. 1613).

After immediate or short-term storage is accomplished at respective processing sites, changes in synaptic efficacy (i.e., consolidation) take place to form long-term memory. The transformation of working memory into long-term memory occurs at the higher stations of modality-specific and polymodal sensory systems, and subsequently at the medial temporal and diencephalic regions of the brain (i.e., areas located between the cerebral hemispheres and the mid-brain), which assemble the temporary information from neurons of respective memory storage sites located elsewhere in the brain (Squire, 1985). The memory system in the medial temporal lobe consists of the hippocampus and its adjacent, anatomically related corticies, which together play an essential role at the time of learning in establishing long-term memory, by binding the distributed sites of memory storage and maintaining the coherence of the whole representation. Knowledge, after reorganization and consolidation, eventually becomes stored in the neocortex, which has the effect of freeing the medial temporal lobe system for further learning or acquisition of new information (Squire & Zola-Morgan, 1991).

In amnesia, premorbid memory is considered vulnerable unless it has been consolidated and has become independent of the medial temporal region (Squire, 1985). Likewise, language knowledge that has not been integrated through competition and consolidation into permanent memory, is presumably more likely to erode in language loss.

Neural Plasticity and Consolidation as Neurobiological Support of the Reverse Order Hypothesis

Taken together, neural plasticity and consolidation of connections seem to provide a plausible explanation for the linguistic characteristics observed in language attrition. The reverse order hypothesis and the inverse relation hypothesis are possible outcomes of the same biological characteristic, neural plasticity, that governs changes in linguistic knowledge. Input frequency, an environmental factor, modifies the linguistic knowledge, which is presumably contained in the dynamic connections of neurons. Linguistic input is processed in parallel and in a modular manner in various sensory cortices, assembled in the medial temporal lobe, and eventually stored in the neocortex as consolidation takes place. Items which are frequent in the input and learned during the earlier stages of acquisition are more likely to have been consolidated and transferred to the neocortex. Infrequent and/or later acquired items, on the other hand, are presumably located in connections in the medial temporal lobe, which are more vulnerable to loss. In essence, information/knowledge is more susceptible to attrition in the order in which it is stored in working memory (i.e., modality-specific processing sites), intermediate memory (i.e., medial temporal region) and finally, permanent memory (i.e., neocortex).

Decreased Accessibility as a Consequence of the Gradual Weakening of Neural Networks

When attrition occurs, there may be an actual loss of some of the neural connections that originally represented acquired information. This view is supported by data on retrograde amnesia (i.e., difficulty in retrieving memories formed before the onset of amnesia, as opposed to anterograde amnesia, which involves difficulty in forming new memories). Many retrograde amnesics have access to their remote, premorbid memory but not to memories of things experienced some weeks or months before the injury. In addition, certain portions of retrograde amnesia are irreversible (Squire, 1985). If we assume that forgetting in amnesia and normal forgetting share an identical biological mechanism, the same rule could be applied to language attrition.

Language attrition, however, is a gradual and global process, unlike amnesia or other abnormalities induced by brain lesions in which immediate and specific deficits of parts of the language system follow. Consequently, people who are in the

process of losing their L1/L2 may initially suffer from a difficulty in retrieving information represented in weakening connections before the information is completely lost. "Relearning" of a language, documented in L1 attrition research (Berman, 1979) and ESL research (Celce-Murcia, 1979, cited in Hatch, 1983) may be the result of a "re-strengthening" of connections which were not completely lost during incubation. "Progressive retrieval" of lexical items observed in language attrition may be instances of weakening connections as well.

Attrition of Declarative versus Procedural Knowledge

It should be noted that the medial temporal region seems responsible only for memory of declarative knowledge. According to Squire (1986), declarative knowledge "is explicit and accessible to conscious awareness," and contrasts with procedural knowledge which is implicit, and "accessible only through performance, by engaging in the skills or operations in which the knowledge is embedded" (1986, p. 1614). Examples of declarative knowledge include facts, episodes, and lists, which can be declared. Procedural knowledge, on the other hand, includes simple forms of associative learning such as classical conditioning and habit. Studies on amnesia have shown that global amnesic patients who have lesions in the medial temporal region are impaired in retrieving long-term declarative knowledge and also exhibit problems in acquiring new knowledge. The amnesic patients' short-term memory and their memory for the very remote past, presumably permanent memory, are spared. Thus, the declarative knowledge lost in amnesia might be more specifically considered as intermediate memory. Such patients also maintain procedural memory, suggesting that procedural memory is a function of different regions of the brain, presumably the striatum, a complex of structures in the forebrain (Squire, 1986) and in the cerebellum (see Robbins, this volume).

If declarative knowledge refers to the ability to explicitly state linguistic rules, naturalistic acquirers of language would have little or not declarative linguistic knowledge. For them, linguistic knowledge, except for semantic knowledge perhaps, would be procedural knowledge. Although procedural knowledge could be represented declaratively as well, the two types of knowledge are stored in separate sites in the brain.

It is plausible to think, however, that procedural knowledge is acquired through stages similar to consolidation of declarative

knowledge. Such stages may involve increasing refinement of skills (Robbins, this volume) and thus, show similar attrition patterns in the reverse order of acquisition, with later stages "undone" first. The mechanism underlying declarative and procedural acquisition and attrition are possibly identical, namely, through modification of neuronal connections, but the location of alteration in the brain may be different in the two types of knowledge. At present, however, neurobiological studies on non-declarative knowledge are too scarce to assess the tenability of such argument.

Neurobiological Support of the Inverse Relation Hypothesis: Efficient Processing and Language Proficiency

Well-acquired items are presumably represented in connections in the medial temporal lobe and the neocortex. Hence, higher proficiency may mean a larger number of consolidated connections in long-term storage. Alternatively, higher proficiency may refer to more efficient connections. In fact, there are studies which show that people with high scores on intelligence tests require less brain energy than people with lower scores. Using positron emission tomography (PET) scans, Haier et al. (1988) measured the intensity of brain activity by recording the amount of an injected substance (a radioactively tagged glucose compound) absorbed by brain cells while subjects engaged in cognitive tasks. Novel tasks increased the amount of energy consumption, but with accumulated practice, brain metabolism decreased significantly. Furthermore, the brain metabolism of proficient task performers was found to be the least active. This finding implies that highly proficient L2 learners may be energy-efficient as well.

Interestingly, Haier and his colleagues noted that a few areas of the brain, including the hippocampus, were activated more after practice. This finding reconfirms the role of the hippocampus as one related to memory and learning. Furthermore, it suggests that more proficient learners are able to utilize information carried in the neuronal networks in long-term storage, and hence, are able to minimize the activation of networks in the initial processing areas in order to accomplish the task.

The brain analyzes new stimuli by comparing it with earlier acquired information and stores the new information in accordance with its similarities and differences to previous memories of the same type. The analysis consists of pattern detection and categorization, which is an important feature of consolidation

(Guyton, 1987; Jacobs, 1991). It follows from this that the richer "internal context" (i.e., prior knowledge) (Jacobs, 1988) one has, the more efficient the interaction with new stimuli will be. Greater efficiency implies the ability to neglect irrelevant information and thus, expend less brain energy.

In sum, proficient L2 learners may have a rich connection of networks in long-term memory which enables energy-efficient processing when acquiring new L2 knowledge. The neuronal connectivity in long-term memory is better developed and more extensive, thus, less immune to loss. In the same vein, the critical threshold of L2 knowledge may correspond to a certain amount and strength of storage in long-term memory which enable acquisition to be more energy conserving.

Neurobiological Support of Residual Learning, Initial Plateau, and Permastore

Since consolidation of memory takes time, language skills may be performed better after a certain lapse of time. For this reason, residual learning may be observed even when language use is discontinued. However, once new information has been reorganized, lack of input will result in the weakening of connectivity. The attrition curve, hence, exhibits an "initial plateau," or resistance to loss, followed by a more rapid and then gradual loss as language disuse continues. At least some portion of the information which has successfully entered permanent memory can be retained in spite of minimal use. Thus, the existence of "permastore" seems possible. Other information can still be retained if language is used, or the information is retrieved frequently enough, to maintain the strength of the connections. Otherwise, lack of input will result in the regression of morphological alterations in connectivity representing linguistic knowledge. Such regression has been observed with animals raised in an enriched environment and then put in an impoverished environment (Diamond, 1988).

Neurobiological Support of the Critical Period of Language Attrition

It has been observed that different regions of the brain have different critical periods of development (Kandel & Jessell, 1991). For example, the development of form perception and the binocular vision necessary for depth perception proceed in stages after birth,

each stage being irreversible. Appropriate sensory experiences are essential for normal developmental processes to occur. Hence, deprivation of appropriate stimulus input during the postnatal period when developmental decisions are being made seems to have the most severe consequences on the maturation of the nervous system in question. Although it has been difficult in the past to relate the development of behavior to the development of the nervous system, studies on the maturation of neurons in the visual cortex have come to provide an important bridge between behavior and the nervous system (Kandel & Jessell, 1991). Discrete stages in the formation of other nervous systems including those related directly to various linguistic skills could ultimately become clearer as well.

The dynamic changes of human dendritic systems triggered by environmental factors have been mentioned above. Dendritic change has also been observed to be age related. Jacobs and Scheibel (In Press) report age related decreases in the length of dendrites emerging from the base of the cell body (i.e., basilar dendrites) and dendritic laterality, loss of dendritic neuropil, especially in the dendritic branches distant from the cell body (i.e., distal segments), and increases in the number of basilar dendritic segments. The study found, interestingly, that the total dendritic length of tissue from the Wernicke's area of nine-year olds was significantly longer than that of any of the adult subjects. Jacobs and Scheibel suggest that major dendritic development takes place through the first decade of life, followed by a gradual decline of proliferation that approximates adult values late in the second decade. Furthermore, Chugani, Phelps, and Mazziotta (1987) point out that cerebral metabolism (i.e., glucose utilization) as well as the size of the major projection neurons in the cerebral cortex (i.e. pyramidal cells), which are indicators of neuronal activity, appear to show parallel age-related changes, reaching maximum measure roughly by the age of 10. The correspondence between neurobiological maturation and the alleged critical period for language attrition is compelling.

Neurobiological substrate of affect

The role of affect in L2 acquisition and attrition appears to have a neurobiological correlate. The almond-sized mass of nuclei called the amygdaloid complex in the limbic system (i.e., the border area arranged around the junction of the cerebral hemisphere with the brain stem), which is located near the tip of the temporal lobe, has been found to be the mediator of the association of memories

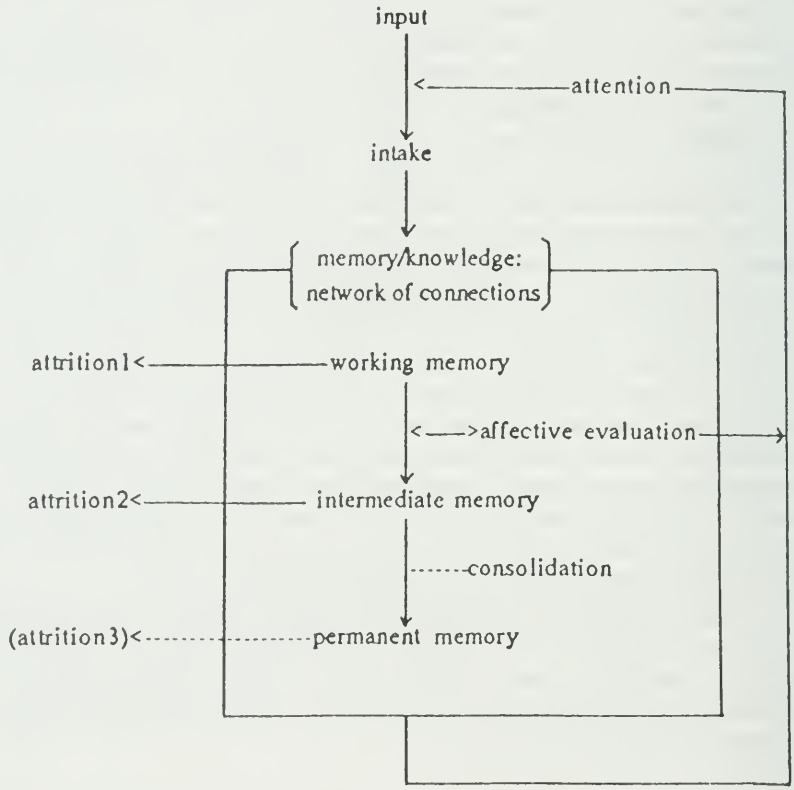
formed through different senses. Although the amygdala in itself is not part of the medial temporal memory system, it establishes links between stimuli through its direct and extensive connections with all the sensory systems in the cortex and attaches affective evaluations to the stimuli. Increased attention to stimuli as a result of the evaluation should lead to more efficient information processing. Thus, it is thought that the amygdala is involved in "selective attention" needed for learning. It appears to limit attention to stimuli with emotional significance (Squire & Zola-Morgan, 1991). The suggestion here is that affect influences what one perceives, and pays attention to, and thus, determines what one learns (Schumann, 1990b; Jacobs and Schumann, 1992) and retains.

Selective attention is relevant in considering why longer exposure to L2 does not necessarily imply higher proficiency and stronger resistance to loss. Studies indicate that cortical network changes are recorded only when input is delivered under attended behavior (Jenkins, Merzenich, Ochs, Allard & Gui-Robles, 1990; La Berge, 1990). Furthermore, it is essential for successful language acquisition and retention that attention be accompanied by sufficient input and use. Based on their experiment on rats, Coleman & Riesen (1968) maintain that certain components of an intact central nervous system may fail to develop normally as a consequence of disuse or decreased input, though there is a degree of dependence on innate organization. Rosenzweig, Love and Bennet (1968) demonstrated that even a few hours a day of removal from impoverished to enriched environment produced significant changes in the brain chemistry and brain weight of rats.

These studies together seem to support findings in language attrition research which indicate that affective factors and selective attention resulting from affective evaluation play significant mediating roles in determining the amount of language use crucial to language retention.

A MODEL OF LANGUAGE ATTRITION

Based upon the integration of relevant issues discussed above, the following schematic representation is presented as a tentative psychological model of the process of language attrition.



Both language acquisition and attrition are consequences of neural plasticity. Neural plasticity allows input to alter the configuration of existing knowledge networks in memory storage. New information is compared with prior knowledge and stored in matched patterns. It is first stored in working memory via modality-specific processing systems, then in intermediate memory where information is integrated and associated with other information, and finally in permanent memory. The transition of information to long-term storage involves consolidation which gradually strengthens certain connections and eliminates or weakens others. Linguistic knowledge represented in eliminated connections is that which is lost. Since memory in permanent storage has gone through consolidation, the connectivity is stronger and, thus, less vulnerable to attrition. Vulnerability to attrition is greatest with respect to recently acquired, unconsolidated knowledge. Information which survives competition and reorganization becomes the basis for the processing of new information.

Figure 1. Neural plasticity allows input to alter the configuration of existing knowledge networks in memory storage. New information is compared with prior knowledge and stored in matched patterns. It is first stored in working memory via modality-specific processing systems, then in intermediate memory where information is integrated and associated with other information, and finally in permanent memory. The transition of information to long-term storage involves consolidation which gradually strengthens certain connections and eliminates or weakens others. Vulnerability to attrition is greater with respect to recently acquired, unconsolidated knowledge. Information which survives competition and reorganization becomes the basis for the processing of new information.

Affect restricts attention to relevant input, and influences the amount of intake. It also determines which information is to be stored in long-term memory. Individual differences in prior experience which define the nature of personal affective evaluations of stimuli determine the formation and strength of connections (i.e., speed and amount of learning), and may even protect certain information (e.g., retention of emotionally laden expressions) during incubation.

The "boxology" adopted in the representation of the model is somewhat misleading since it depicts the types of memory storage as being separate entities. The same synaptic connection within a given neuronal network may correspond to any length of memory storage, depending on the strength of the connections. The psychological terms working, intermediate, and permanent memory, are distinguished, however, in order to reflect the neurobiological findings which indicate presumably separate sites of storage roughly corresponding to the three types of memory.

Affect restricts attention to relevant input and influences the amount of intake. It also determines which information is to be stored in long-term memory. Individual differences in prior experience which define the nature of personal affective evaluations of stimuli determine the formation and strength of connections (i.e., speed and amount of learning), and may even protect certain information (e.g., retention of emotionally laden expressions) during incubation. Thus, length of exposure alone does not necessarily determine proficiency or achievement.

Certain groups of connections form a system which becomes the unit for higher-order connections. Different systems have different critical periods of development, and input during such periods has the greatest influence on the nature and structure of connections to be formed. Little is retained if input is received only during the immature stages of the relevant system that processes and stores that kind of input.

A theory of language attrition should subsume or be compatible with a theory of language acquisition (Schinke-Llano, 1989). The present model, accordingly, assumes that the biological mechanism that governs language acquisition and attrition in both L1 and L2 or, for that matter, in any language, is by and large identical. Differences in the characteristics of the actual behavior observed in language acquisition and attrition, or in L1 and L2, are mostly due to the different environmental factors that have contributed to the formation of idiosyncratic neurobehavior at different developmental stages and under different affective conditions. Connections are input-dependent, but the mechanism that keeps records of the input and retains them in long-term memory in association with other input items, features, or relationships may be innate.

Although the present model is a psychological one, the intention has been to emphasize the significance of considering available information from neurobiology and relating that to psycholinguistic research on language attrition. With further advances in neurobiological studies, the construction of a

neurobiological/neuropsychological theory of language acquisition and attrition should become feasible.

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NOTES

[1] The loss of L2/FL can further be subcategorized into two types; L2/FL lost in the L2 environment such as in the case of aging emigrants/immigrants, and L2/FL lost in the L1 environment such as in the cases of language learners at school of returnees from countries where the FL is spoken.

Language attrition studies may ultimately need to distinguish the two types of language learning. There is, however, not enough literature on language attrition that makes the distinction feasible at this point. Furthermore, my view on language attrition is that the governing mechanism of linguistic behaviors is identical whether the language is L1, L2, or FL. I will argue later in the paper that what makes the difference are the cognitive, developmental, socio-psychological, and environmental factors that are concomitant to the L2/FL distinction. Thus, in the present paper, I do not intend to make an explicit distinction between L2 and FL loss.

[2] This section is a condensed version of a lengthier and more comprehensive review of literature of L2 attrition summarized in Yoshitomi (1992). Some oversimplifications of issues were inevitable due to the specific focus of the present paper and space limitations.

[3] Although a more detailed discussion of the investigation of language abilities in brain damaged persons in relation to language loss would be a useful exploration, this paper will limit itself to a brief mention that intriguing similarities exist between pathological and non-pathological language less. Future research should certainly address this issue further.

[4] For more discussion on selective attention, see Sato and Jacobs or Lem, this volume.

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