Implicit Learning and Aging

by

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Abstract

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Reber's (1993) evolutionary theory of the cognitive unconscious posits that implicit learning should be more resistant to age-related decay than explicit learning. The goal of the study was to assess the effects of aging on implicit learning. Thirty one aged participants and 80 college undergraduates completed implicit and explicit learning tasks. The implicit task was a version of the Artificial Grammar (AG) paradigm and the explicit learning task was a sequence completion task. Participants were also assessed for processing speed and Working Memory (WM). The older participants were both slower and less accurate on the implicit and explicit tasks and were dramatically slower on the processing speed measures than the college undergraduates, but no age differences were found for the WM measures. Interpretation of the results from the explicit task were fairly straightforward, as age deficits were anticipated and revealed by the data. The results from the AG task however, raise many intriguing questions as the age deficit was not anticipated. Some of the other findings are used to explain the age deficit in AG performance. The younger participants often reported accurate explicit knowledge for some of the rules used in the artificial grammar, while the older participants tended to report little or no explicit knowledge of the rules. It is argued that the inability of the older adults to acquire explicit knowledge of the AG contributed to the age deficit. Furthermore, the results from a series of correlations performed between the processing

speed measures and implicit and explicit task performance also suggest that processing speed is related to the AG performance of the older participants. These results are discussed in relation to the current theories of aging and implicit learning.

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Chapter 1

Theories of Implicit Learning and Aging

Herman Ebbinghaus once described psychology as having "a long past, but only a short history" (Ebbinghaus, 1910, p.9). The same can be said about the notion of unconscious mentation. For centuries, hypotheses about the possible influences of unconscious processing have been offered from various theorists, yet the empirical investigation of these processes is relatively new. In the aftermath of the cognitive revolution, the cognitive unconscious, although still an extremely controversial topic, has become an increasingly important area of study. However, there are several gaping holes in the theories of unconscious mentation. Developmental research has effectively demonstrated that children rely greatly on implicit processing in the development of physical, linguistic, social, and cultural skills. Furthermore, it is likely that the implicit system, which is proposed to be more resistant to age-related decay, contributes greatly to overall processing among the elderly, in light of the wear and tear that age is known to impose on the explicit system. Nevertheless, researchers have yet to integrate theories of the cognitive unconscious into a dynamic investigation of the contributions of implicit functions to cognitive development across the lifespan. This paper will review and assess the available literature on the effects of age on implicit learning and attempt to assimilate the differing views and research goals held by developmental and cognitive theorists, utilizing functionalist principles of evolutionary biology.

Implicit Learning Theory

Some background information on the popular implicit learning paradigms and theories is required before initiating any meaningful discussion of the available research

on the effects of age on implicit functioning. Implicit learning has generally been recognized as the process by which knowledge of the underlying structure of complex stimulus environments is obtained, largely without awareness of either the process or the products of the acquisition (see Reber 1967, 1993). Implicit learning and other processes generally regarded as falling within this same perceptual, cognitive domain are often contrasted with the more frequently studied explicit processes, which are conscious, reflective, and whose knowledge base can be sufficiently articulated.

The prevailing view on consciously modulated, more deliberative processes such as problem solving and memory retrieval is that they show dramatic shifts across the lifespan. That is, they are largely absent during infancy, develop slowly during childhood and adolescence and taper off in old age.

In contrast, it has been theorized that implicit processes demonstrate little in the way of age-related changes. There is considerable evidence to support the primacy of implicit mechanisms during infancy and childhood (Saffran, Aslin, & Newport, 1996; Saffran, Newport, & Aslin, 1996; Gomez & Gerkin, 1999) and additional findings suggesting that such unconscious processes function independently of top-down mechanisms (see Reber & Allen, 1999 for a review). Some studies provide support for a similar resistance to the effects of aging (Howard & Howard, 1989, 1992, 1997). These latter studies, however, present a distinctly mixed set of findings. Some studies have found similar performance for elderly and college-aged populations on implicit learning tasks (Howard & Howard, 1989, 1992; Meulemans, Van der Linden & Denis, 1996). Others have reported that an aged population did, in fact, show diminished performance

on implicit tasks (Cherry & Stadler, 1995; Frensch & Miner, 1994; Howard & Howard, 1997).

One difficulty in generalizing across these experiments is that several different procedures are commonly in use, and there are reasons for suspecting that each invites a mix of implicit and explicit processing (Neal & Hasketh, 1997, Shanks & St. John, 1994). The two most commonly employed implicit learning paradigms are artificial grammar learning (AG) and the serial reaction time (SRT) task. Artificial grammar learning experiments typically consist of an initial learning phase during which subjects memorize a series of "grammatical" strings formed according to a set of complex rules and a testing phase in which subjects are presented with a set of new strings and are asked to determine whether or not the new strings follow the same set of rules as the memorized strings. Participants are usually able to determine, at levels better than chance, which strings are grammatical, but demonstrate little or no declarative knowledge of the grammar.

Serial reaction time (SRT) experiments assess subjects' abilities to learn a repeating sequence or a rule generated pattern of lights that flash in a spatial array. Participants' responses to the patterned light flashes tend to get faster. Implicit learning is demonstrated by dramatic increases in reaction time (RT) when the structured sequence is replaced by a different (often random, or semi random) sequence. The sudden increase in RT after the sequence is changed demonstrates that the faster RT's were produced by the learning of the sequences and not simply by motor learning (getting faster at pressing the keys).

In both the SRT and AG tasks, the knowledge reported by subjects usually cannot account for their success on the task. In fact, many subjects report being unaware of

having learned anything, suggesting that these tasks were learned implicitly (for different views see Dulaney, Carlson & Dewey, 1984; Perruchet & Pacteau,1990; Shanks & St. John, 1994).

An Evolutionary Theory of Implicit Learning

Several attempts have been made to include the notion of unconscious mentation into a larger theoretical model. Reber (1992, 1993) argues that implicit processes should be analyzed within the context of adaptationist principles of evolutionary biology and should be viewed, in terms of ontogeny, phylogeny and function, and not simply in descriptive terms. Reber draws on several ideas proposed by Schank and Wimsatt (1987) in their discussion of the application of evolutionary biology to developmental theory. Schank and Wimsatt discuss a number of concepts which provide the theoretical context with which to understand Reber's theory. They posit that evolution is a pyramidal, hierarchal process in which features that emerge earlier in development are considered evolutionarily older, and are therefore thought to be more resistant to change. Moreover, the longer features persist, the more additional features become dependent upon them, resulting in enhanced resistance of the older features to change.

In his evolutionary model, Reber (1993) postulates that "consciousness is a late arrival on the evolutionary scene... and sophisticated unconscious perceptual and cognitive functions preceded its emergence by a considerable margin" (p. 86). It is argued that the implicit takes primacy over the explicit and therefore, the implicit system should be more robust than the explicit system and "can also be expected to be relatively independent of age and developmental level" (Reber & Allen, 2000, p. 11).

The evolutionary theories of implicit functioning allow for a more comprehensive understanding of implicit processes such as implicit learning, however, they are not very helpful in providing an understanding of the differential contributions of each system to overall development. Several theories offered by developmentalists at least partially account for the emergence of both implicit and explicit processes, however, they have been narrow in scope, focusing primarily on the hypothesized dissociation of the two systems and failing to provide insights as to how these systems contribute differentially and interactively towards cognitive development (e.g. Gomez & Gerkin, 1999; Haith, Wentworth, & Canfield, 1993; Saffran et al., 1996a, 1996b). Although developmental and cognitive theorists are attempting to elucidate the functions and mechanisms of implicit processing (most developmental researchers have maintained a bias toward implicit memory), the two research branches have yet to join forces in creating a solid theory of development that effectively utilizes and accounts for unconscious processes (see Vinter & Perruchet, 2000). Similarly, despite numerous aging experiments which have demonstrated various cognitive dissociations such as those between item and source memory (Glisky, Polster, & Routhieaux, 1995) and direct (some would say explicit) and indirect (some would say implicit) memory (Light, LaVoie, Valencia-Laver, Albertson, Owens, & Mead, 1992) a convincing theoretical model explaining the effects of aging on implicit functioning is lacking.

The Robustness of Implicit Learning

While evidence for the age independence of implicit processing is relatively sparse, studies have been conducted which support the position that implicit learning remains relatively intact even when explicit learning is compromised by cognitive

deficits. Abrams and Reber (1988) found that a group of psychotic psychiatric inpatients performed as well as college students on an implicit AG task, while showing major deficiencies in performance on an explicit problem-solving task with performance essentially at chance. In addition, Knowlton, Ramus, and Squire (1992) report a sample of amnesics demonstrating fully intact AG implicit learning. However, when the task was altered and explicit instructions were provided, the performance of the amnesics was reduced to chance levels. Knopman and Nissen (1987) provide further support by showing that Alzheimer's patients were able to implicitly learn the repeating patterns in an SRT task. Recently, Smith, Siegert, and McDowell (2001) demonstrated preserved implicit learning among Parkinson's disease (PD) patients on both an AG and SRT tasks. This finding is contrary to their original hypothesis which predicted the PD participants would show intact AG learning, and deficient SRT learning caused by the strong motor component of the SRT task. These and numerous other experiments (see Reber, Allen & Reber, 1999; Ferraro, Balota, & Connor, 1993; Nissen & Bullemer, 1987) provide ample support for the hypothesis that the implicit system is more robust than the explicit system.

The Age Independence of Implicit Learning

Inspired by the evidence supporting the robustness of implicit processing in the face of various cognitive disorders, many researchers are now focusing on the effects of age on implicit processing. Reber's (1993) evolutionary theory hypothesizes that implicit processing should function relatively independent of: (1) developmental level and (2) age. Therefore, it is predicted that infants and children should show more advanced implicit than explicit processing while elderly participants would be expected to demonstrate less of a decline in implicit processing than explicit processing.

Implicit processes in early development: Experiments and theories.

It is clear that infants and children utilize implicit processes throughout development. Infants acquire tremendous amounts of information about their physical, social, cultural, and linguistic environments, and they do so quickly, efficiently and, as far as we can tell, without conscious awareness (Reber, 1993). Several recent studies have tested infants' abilities on variations of both the SRT and AG tasks. Haith et al. (1993) demonstrated that in a simplified SRT task, 3-month-old infants learned to anticipate alternating and repeating visual patterns. In a study conducted by Gomez and Gerkin (1999), 11 and 12-month-old infants were capable of learning an artificial grammar (it is assumed they did so implicitly). Finally, Saffran et al. (1996a, 1996b) report that 8-month-old infants were able to incidentally learn arbitrary patterns of phonetic variations. This last investigation is especially interesting as the infants performed as well as an adult comparison group on the task. Together, these studies suggest that infants as young as 3 months are capable of implicitly learning patterns of co-variation. Furthermore, based on the findings of Saffran et al. (1996a, 1996b), it seems plausible that infants as young as 8 months can learn these tasks as well, or almost as well as adults.

Recently, Vinter & Perruchet (2000) tested a large sample of children between the ages of 4 and 10 using the neutral parameter procedure, a novel implicit learning paradigm based on drawing behavior and the "start-rotation principle" (Van Sommers, 1984) which states that when drawing closed geometrical figures such as triangles and circles, the starting position influences the direction of drawing movement. For example when drawing a circle, if the starting point is set below a virtual axis going from 11 to 5

o'clock, subjects tend to draw in a counterclockwise direction. During training, the participants were given an image to sketch and a specific direction to begin drawing. The vast majority (80%) of the starting points were associated with a drawing direction which was incongruent to the start-rotation principle. Learning was evident through demonstrated preferences for the trained starting point-rotation contingencies over the start-rotation principle preferences. Vinter and Perruchet showed that age did not impact implicit learning performance, and confidently concluded that implicit learning processes are age independent.

The majority of studies suggest that age has little or no effect on implicit learning task performance, however, some findings demonstrate age-related improvements in children on implicit learning tasks. Mayberry, Taylor, and O'Brien-Malone (1995) tested low, medium and high IQ children from two age groups, 5 to 7 and 10 to 12 year olds, with an implicit hidden-covariations task. For this task, participants searched for a specific target image among various distracter images in a matrix. Cues as to the location of the target were provided by the location of the experimenter presenting the stimulus cards (correlated to the top or bottom of the matrix) and the color of the cards (each color corresponded to a different side of the matrix). In this study, the older children outperformed the younger children. However, it is necessary to exercise caution when interpreting these results as the age-related deficits demonstrated by the younger children may have resulted from factors such as attention and strategic cognitive control mechanisms, and not necessarily from a lesser developed implicit system.

Implicit memory is a parallel line of research which has been gaining influence over the past few decades. Research on implicit memory is not concerned with the

acquisition of knowledge; its focus is on the processes of storage and retrieval. Implicit memory is thought to occur when a previously presented stimulus influences behavior, despite the fact that the subject has little or no explicit memory of the stimulus. The AG task is considered an implicit learning task because participants accumulate knowledge of the grammar and are capable of using this implicit knowledge to determine whether novel strings are grammatical or not. In contrast, implicit memory tasks, such as repetition priming experiments, require no acquisition of knowledge. Nothing new (like the grammar in the AG task) is learned or remembered in these tasks, however, the stimulus presented in implicit memory tasks can affect behavior (by serving as primes), regardless of the fact that they were not consciously encoded.

Implicit memory has been studied intensively by developmental researchers. Consequently, there is a wealth of evidence supporting the notion that implicit memory is not dramatically altered throughout childhood development. A particularly revealing developmental study of implicit and explicit memory was conducted by Wippich, Mecklenbrauker and Brausch (1989). Children aged 5 to 8 displayed no differences on implicit priming tests, while older children demonstrated superior performance on the explicit recall and recognition memory tasks.

The vast majority of evidence obtained from implicit processing studies with children supports the hypothesis that these processes function largely independent of developmental level. Perruchet and Vinter (1998) argue that "the recent upsurge of research on implicit learning provides a unique opportunity for a theoretical integration of the issues raised in the learning and developmental areas" (p. 496). There have been a

few attempts to integrate unconscious processes into a larger model of cognitive development.

Karmiloff-Smith (1992) claims that children first develop an implicit system and through this system gain implicit knowledge of the world. The explicit system begins to emerge at a later stage, where implicit knowledge is redescribed into explicit knowledge. In other words, Karmiloff-Smith posits that initially infants are born with an implicit system, and that the explicit system emerges subsequently in development, and is constructed in part by the implicit knowledge base.

Mandler's (1992) model of development differs from Karmiloff-Smith's (1992) model in that it claims infants possess both an implicit and explicit system, with the implicit system dominating processing early on. Therefore, at the earliest developmental level, nearly all of an infant's knowledge is based on perceptual information (this information can be thought of as implicit knowledge). As the child develops and the explicit system gains prominence, much of the perceptual schemas produced by the implicit system are redescribed into conceptual propositional knowledge (or explicit knowledge).

Perruchet and Vinter (1998) embrace the idea that information from the implicit system may be recoded into explicit knowledge, but they believe that this occurs without the abstraction of implicit knowledge. On the surface, it seems like Perruchet's theory of implicit learning has little to offer developmental theory as long as the notion of implicit knowledge is rejected. However, Perruchet postulates that the rejection of implicit knowledge is precisely what his theory of implicit learning offers. Instead of focusing on implicit knowledge, both implicit learning and developmental theorists should be

focusing on the processes by which implicit learning systems change the explicit knowledge base. Perruchet argues that the function of the implicit system is to process the "primitive features" of a stimulus so that they may eventually provide a "conscious coding of the material that is increasingly relevant to the structure of the task" (P. 503). Assuming that Perruchet's conception of implicit learning (without implicit knowledge acquisition) is correct, it can be argued that developmental theories should expunge the notion of implicit knowledge (be it abstract or symbolic knowledge) and further emphasize the role of the implicit system in amending the explicit knowledge base.

The notion of implicit learning in the absence of knowledge acquisition is highly controversial. The majority of developmental (including Karmiloff-Smith, 1992 and Mandler, 1992) and implicit learning theorists believe that implicit knowledge exists and is a major contributor to the learning of new tasks. Reber (1993) cites a series of studies that succeed in demonstrating at least some implicit knowledge in adults. In these "transfer" studies, subjects learn an AG with a single letter set, and then after a varied duration of time, a new letter or stimulus set with the same grammar is employed. Subjects in these experiments demonstrate negligible explicit knowledge of the task, but do show transfer learning. This transfer effect suggests that participants have implicitly acquired at least some abstract representations of the grammar allowing them to transfer their implicitly acquired abstract knowledge base to a novel stimulus set. Although the effect is usually weak, it has in fact been demonstrated in several studies (e.g., Reber, 1969; Mathews et al, 1989; Manza & Reber, 1997). These experiments suggest that implicit knowledge is abstracted in implicit learning tasks, and therefore, theories of the

development of implicit processes should include the notion of implicit knowledge acquisition.

Perruchet and Vinter (1998) deserve recognition as they are among the first researchers to attempt to synthesize developmental and implicit learning theory. However, their conception of the interplay of the two systems, where implicit learning influences explicit knowledge without any abstraction of implicitly acquired information, is problematic. If there is no implicit knowledge what possible impact can the implicit system have on the explicit system? The need for further theorization and investigation of the effects of development on the implicit systems is evident. Overall the preliminary findings have been encouraging and suggest age independence in implicit processes through childhood. In addition, theoretical progress has been made such that developmental theories are now beginning to account for implicit processes (for another example see Steffler, 2001).

Implicit processes at the other end of the lifespan.

Relative to the research on the development of implicit processes, the empirical and theoretical picture for older participants is less clear. Research on the effects of aging has focused primarily on explicit processes which have been shown to decline with age (Salthouse & Craik, 2000). Reber's evolutionary theory predicts that implicit processes should not be as affected by age as explicit processes. Perhaps, because it is the goal of most researchers to discover the processes that diminish with age, and it is expected that the implicit system should remain relatively intact, researchers have been reluctant to conduct implicit processing experiments with elderly populations. Fortunately, there have

been some pioneering studies which have attempted to discover the effects of aging on implicit processing, however, these studies offer a mixed bag of results.

Several experiments assessing the effects of aging on implicit and explicit memory demonstrate an age-related deficit in implicit memory (see e.g. Chiarello, & Hoyer, 1988; Light & Burke, 1988; Light, 1992). However, in a review of the literature, Shimamura (1990) concluded that in general, implicit memory is more resistant than explicit memory to the effects of aging.

Empirical investigation of the effects of aging on implicit learning processes is nascent, and as of yet has produced encouraging results. A study conducted by Meulemans, Van der Linden, and Denis (1996) employed the AG paradigm to investigate implicit learning in older subjects. The results indicated that age did not influence AG learning, although the sample was fairly young (mean age = 64). D'Eredita and Hoyer (1999), tested subjects aged 45-65 years and found age-related deficits on a variation of the AG task, but their AG task was dramatically different from the standard AG task. For example, the subjects were never told that there was a grammar and in the testing phase were asked to complete an incomplete string with a grammatical sequence rather than simply judge whether a given sequence is grammatical or not. It can be argued that this task has a stronger explicit learning component to it than the standard AG task, and was not a good measure of standard AG implicit learning.

There are several experiments utilizing SRT tasks to investigate the performance of aged subjects. Howard and Howard (1989, 1992, 1997) have conducted a series of revealing studies. They report that, although aged adults had slower RT's overall, they showed similar learning to young adults on a repeating pattern SRT task with second-

order dependencies built into the sequence (Howard & Howard; 1989, 1992). These studies also revealed age-related deficits on an explicit component of the task where subjects were asked to generate or predict the location of the stimuli. Interestingly, Howard and Howard (1997) have also shown that younger adults (19-21 years) outperformed both old (65-73) and old-old (76-80) adults on a more difficult SRT task with higher order (third and fourth order) dependencies built into the sequence. The results from this study suggest that the age difference on this task resulted from the older subjects diminished sensitivity to the higher-order dependencies.

It has been argued that although older participants demonstrate implicit learning on the standard SRT task, deficits in SRT learning can arise under certain circumstances. Frensch and Miner (1994, experiment 3) report age-related deficits in a complex SRT task. They tested young (mean age = 18.8) and old (mean age = 73.7) adult subjects on an SRT task with either a single task condition or a dual task condition. In the dual task condition the primary task was to locate the standard visual stimuli (an asterisk), and the secondary task had the subjects discriminate between a series of high and low pitched tones by counting only the high pitched tones (see Cohen, Ivry, & Keele, 1990). Frensch and Miner (1994) found that while there were no age differences in the single-task condition, there was an age deficit in the dual task condition with the older adults showing poorer sequence learning.

Together, the results from Howard and Howard (1997) and Frensch and Miner (1994) suggest that, at least in complex versions of the SRT task, age-related deficits can arise. However, these results must be interpreted cautiously as several factors other than a deficient implicit learning system may have confounded the results. For example, age-

related differences in attentional capacity, (see, e.g. Plude & Hoyer, 1985) working memory (see P. J. Reber & Kotovsky, 1997), and cognitive slowing (see, e.g. Salthouse, 1991, 1994, 1996) may have contributed significantly to the age deficits.

Cherry and Stadler (1995) conducted a study in which old (age = 67.5 years) and young (age = 22.9 years) participants were further divided into groups differing in occupational status, educational attainment, and verbal ability. Overall, they found that the younger adults and high ability older adults showed more SRT learning than the low ability older adults. Furthermore, the young adult and high ability old adult samples outperformed the low ability older adults on an explicit learning task. These findings are weakened by the failure of the researchers to screen the aged participants for Alzheimer's disease or for Pre-Clinical Dementia (PCD) (Sliwinski, Lipton, Buschke, & Stewart, 1996). It is possible that the low ability old adult groups included many participants who were suffering from undiagnosed Alzheimer's disease or PCD.

Collectively, these findings suggest that observed deficits in implicit learning are likely related to external factors such as age and educational status, as well as internal factors including processing speed and short-term memory capacity. It is possible that additional demographic factors may be related to deficits in implicit functioning. On the surface, this seems problematic for Reber's (1993) evolutionary theory because it predicts that implicit performance: (1) should be less variable than explicit performance, (2) should not be related to individual factors such as educational status, and (3) should be relatively independent of age. However, these findings are far from devastating to the theory. It may be true that implicit processes show signs of aging and are dependent on several other factors including educational attainment and cognitive ability, but, the

evidence suggests that implicit processes are more resistant to decay and are not as affected by these factors as explicit processes. Furthermore, the influences of internal factors such as processing speed and working memory capacity hang about as a pesky confound in all studies comparing implicit and explicit learning task performance.

Hoyer and Lincourt (1998), in a review of the available research on implicit learning and aging, attempt to employ what is currently understood about the effects of aging on learning to gain a better understanding of the age differences in implicit and explicit learning. In contrast to Reber and Allen (2000) who propose that the implicit system is separate from the explicit system, Hoyer and Lincourt claim that:

> "Age-related differences in implicit learning and explicit learning are probably best understood in terms of age-related differences in the efficiency of processing speed and particular mechanisms (e.g. chunking or unitization, associative learning, instance based learning). These age sensitive mechanisms provided a satisfactory account for observed age differences in the course of implicit learning and explicit learning, and for the lack of age differences on simple or well learned implicit or explicit tasks" (pp. 464-465).

These arguments are supported by the recent conclusion of Salthouse, Mcgurthy, & Hambrick (1999) that "typical measures of implicit learning... do not reflect a qualitatively distinct type of cognitive processing nor do they seem to exhibit additional compensatory age-related influences" (p. 1).

There is clearly some merit to the above stated position. However, additional research is required for a true assessment of the theory. To date, there are too few studies to draw definite conclusions regarding the effects of aging on implicit learning, although existing studies indicate less of an age-related decline in implicit learning than explicit learning (Cherry & Stadler, 1995; Frensch & Miner, 1994; Howard & Howard, 1989,

1992, 1997; Meulemans et al., 1996). Moreover, the argument that the same processes contribute to age-related deficiencies in both implicit learning and explicit learning has not been subjected to strong experimental testing.

A great deal of empirical evidence indicates a dissociation between implicit and explicit processes. As mentioned earlier, there is a wealth of data demonstrating that the implicit system is more robust in the face of neurological decay than the explicit system (see e.g., Abrams & Reber, 1989, Ferraro et al., 1993; Knopman & Nissen, 1987, 1991; Knowlton et al., 1992; Nissen & Bullemer, 1987). Furthermore, results from neurological studies offer additional support for the view that the implicit and explicit systems rely on different neural mechanisms. The implicit system appears to depend on the integrity of the striatum, cerebellum, amygdala, and neocortex, while the explicit system is associated with activity in the medial temporal lobe, limbic and diencephalic structures (e.g., Baldwin & Kutas, 1997; Gabrieli, 1994; Seger, 1994; Squire, Knowlton, & Mussen, 1993; also see Curran, 1998). In addition, it is likely that the neural mechanisms which contribute to implicit learning and memory, are relatively unaffected by aging, and the types of disorders (e.g., Alzheimer's and Korsakoff's disease) that affect explicit learning (see Curran, 1995; Rybash, 1996; Squire, et al., 1993). In summary, it seems that Hoyer and Lincourt's (1998) assumptions, that aging leads to significant decay in implicit processes and that the same processes contribute to age-related deficits in implicit and explicit processes, may be premature.

In a contrasting view, Reber and Allen (1999) postulate that the implicit system is distinct from the explicit system, and that the usual declines associated with aging in explicit processes, such as memory and problem solving, should not arise with implicit

processes. They propose that when age-related declines are found, "secondary factors such as attention and motivation are likely to be playing a role" (p. 235). Unfortunately, to date there is little empirical support for this theory. The studies that have shown age differences in implicit processing have yet to provide insights into the causes of these deficits. It is evident that additional research investigating the effects of aging on implicit learning is necessary. Although there is a wealth of evidence supporting the notion that the implicit system is more robust than the explicit system, the evidence for or against the hypothesized age independence of implicit learning is sparse. The studies that have been carried out suggest that there are differences in performance between older and younger subjects on implicit learning tasks, but the sources of the differences remain obscure. A majority of the theories of implicit learning and aging have been concerned exclusively with either supporting or refuting the proposed dissociation between the implicit and explicit systems. Unfortunately, this strategy provides little insight into what the currently available theories of aging have to offer with regard to age-related effects on implicit task performance and any differences in performance by aged populations on explicit and implicit tasks.

Theories of Aging

Research on the cognitive declines associated with aging is rapidly emerging, and as a result, several theories of aging have been proposed and subjected to intense empirical scrutiny. This section will briefly review three of these theories and whenever possible, attempt to employ them to gain a better understanding of the effects of age on implicit processes such as implicit memory and implicit learning.

Cognitive slowing.

One of the more prominent theories of age-related cognitive decay is the cognitive slowing hypothesis advanced by Salthouse (1994, 1996). A major component of the theory is that a breakdown in a specific process can lead to global processing deficits, and can therefore account for the vast majority of age-related variance on cognitive tasks. After conducting a series of experiments and collecting a mass of data, Salthouse (1996) hypothesized that:

> "increased age in adulthood is associated with a decrease in the speed with which many processing operations can be executed and that this reduction in speed leads to impairments in cognitive functioning because of what are termed the limited time mechanism and the simultaneity mechanism. That is, cognitive performance is degraded when processing is slow because relevant operations cannot be successfully executed (limited time) and because the products of early processing may no longer be available when later processing is complete (simultaneity)" (p. 403).

The limited time mechanism predicts slower response times on all tasks and a more pronounced speed-accuracy tradeoff in complex cognitive tasks. The simultaneity mechanism predicts that increasing allotted time will not always benefit aged participants, as performance deficits may be rooted in internal (processing speed) and not external (stimulus presentation time) factors. For example, the simultaneity mechanism can create deficits in working memory capacity, as each processed item remains in working memory for longer intervals, burning up more of the available cognitive resources. In this case, increasing stimulus presentation time would have little or no impact on increasing working memory capacity. Cognitive slowing leads to slower activation and processing of information, allowing fewer items to be processed within working memory, and because information in working memory is processed slowly,

higher order processes (abstraction, integration etc.) are limited as well. Various theories have asserted that working memory capacity is reduced with age (Hasher & Zacks, 1988). The limited working memory capacity theory will be discussed shortly in greater detail, however, it is worth noting that the simultaneity mechanism provides an alternative scheme for explaining empirical findings, as it also explains reductions in working memory capacity among aged samples.

The cognitive slowing hypothesis has become an extremely popular tool for explaining age-related variance, and numerous studies offer support for Salthouse's (1994, 1996) conclusions. Although there is little doubt that response times are slowed by aging, the strongest evidence for cognitive slowing comes from meta analytic studies showing that processing speed accounts for a high proportion (about 75%) of the age-related variance, and that after controlling for processing speed, other proposed factors, including working memory, show a substantially weaker relationship to age-related cognitive declines.

Despite the growing strength of the cognitive slowing hypothesis, recent findings call some of the major assumptions of the theory into question. In a longitudinal study, Sliwinski and Buschke (1999) tested an aged sample (mean age at baseline testing was 77.2) at 18-month intervals for up to five tests. They found that when their data were analyzed with cross-sectional models, processing speed accounted for a large proportion (75%-100%) of the age-related variance on other cognitive tasks. However, when longitudinal models were used, although processing speed correlated with performance on other cognitive measures it accounted for much less of the age-related variance (6%-29%). Several explanations can be offered to explain how a longitudinal design can yield

different results than a cross-sectional design. Selective attrition, where participants who remain in the study are more likely to have superior processing ability, and cohort effects, where participants in different cross sections are likely to differ substantially, are two possible culprits. Nevertheless, the study suggests that while speed of processing accounts for much of the age-related variability between groups, it may not be as important in accounting for age-related variance within groups. It is not clear why or how the longitudinal study conducted by Sliwinski and Buschke created such a different empirical landscape, but their findings offers some healthy opposition to the promoters of cognitive slowing.

Limited capacity or failed inhibition within working memory?

One of the earliest theories of age-related processing decay is the limited capacity theory proposed by Hasher & Zacks (1988). This view asserts that a decline in the capacity of working memory is responsible for much of the age-related variance found among the elderly. The theory is useful in explaining age-related declines in a wide variety of tasks (see Zacks & Hasher, 1988; Zacks, Hasher, Doren, Hamm, & Attig, 1987). However, its limitations are apparent, as it has been extremely difficult to quantify working memory storage capacity. Consequently, the actual source of the working memory deficit has been difficult to pinpoint (Stolzfus, Hasher, & Zacks, 1996). As such, many researchers have modified their views of working memory and its contributions to age-related cognitive processing declines. Hamm and Hasher (1992) proposed that a breakdown of inhibitory mechanisms is the root cause of age-related declines associated with working memory processes. According to this view, age-related declines in working memory tasks are thought to arise from a breakdown in inhibitory mechanisms which

inevitably lead to a working memory system overload and degraded performance on working memory tasks. Proponents of this model have shown that under certain circumstances, elderly groups demonstrate capacity levels similar to young groups, but problems in responding arise when distracting stimuli interfere with the processing of task relevant stimuli (Hamm & Hasher, 1992). These findings demonstrate the effectiveness of the inhibitory view in explaining much of the age-related variance on working memory tasks.

A recent study by Oberauer (2001) suggests that "older adults have specific difficulties rejecting intrusions from irrelevant information in long-term memory" (pp. 956-957), however, the older adults showed no clear deficits in working memory capacity. These findings are potentially important because they offer insights into the source of age-related variation in working memory processes. Despite these convincing findings, proponents of the limited capacity view persist (see Light, 1991). These competing views can be readily synthesized. It is plausible, and perhaps even probable, that aging causes both a reduction of working memory capacity and a breakdown of inhibitory mechanisms, and that together these processing deficiencies lead to degraded performance in working memory tasks (Hamm & Hasher, 1992).

The de-differentiation theory of aging.

Consensus is extremely rare in psychological research and practically nonexistent in theories of aging. However, there is agreement that sensory functions decline significantly with age. What remains in dispute is whether age-related declines in sensory functioning are significantly associated with performance on various cognitive tasks. While the majority of researchers argue that sensory decay is not related to cognitive

decay, proponents of the de-differentiation theory of aging argue that the sensory decay associated with aging is somehow linked to age-related declines on cognitive tasks. It is worth noting that a similar debate occurred among the early intelligence researchers such as Galton and Cattell, who concluded that sensory function is not related to intelligence. There is no consensus on this issue, as it relates to aging. Salthouse (1996) demonstrated that the two major sources of age-related variance in a battery of cognitive functioning measures were cognitive slowing (nearly all of Salthouse's findings promote a cognitive slowing effect) and visual acuity. Further evidence for the view that sensory decay may contribute to cognitive declines was advanced by Baltes and Lindenberger (1997). In a large sample of participants (n = 687) spanning in age from 25 to 103 years old, "the link between fluid intellectual abilities and sensory functioning, albeit of different size, displayed a similarly high connection to age [across] age groups" (p.12). The researchers conclude that the age-related cognitive declines associated with sensory declines may be the result of "brain aging" which affects both sensory and cognitive processing mechanisms. Proponents of the de-differentiation theory of aging have hypothesized that early in development, children begin to differentiate by demonstrating individual differences in cognitive ability. These differences intensify throughout adulthood until the end of the lifespan, when the debilitating effects of age emerge and the aged now begin to de-differentiate, displaying fewer individual differences in cognitive ability. It is further postulated, that while the variance of cognitive ability between individuals should decline with age, variance of cognitive performance within individuals should begin to increase at the end of the lifespan.

If there is a consensus on this issue, it is probably that age-related declines in sensory processes are independent of age-related cognitive declines (see Anstey, Hofer, & Luszcz, 2003), however, the notion that sensory decay and cognitive decay are both caused by "brain aging" is very compelling, but only if we can operationally define "brain aging" in useful terms. Recent studies have provided additional support for the de-differentiation theory of aging (see Li et al., 2004). Additional research is needed to combat the wealth of evidence showing no association between cognitive ability and sensory functions. However, the above stated findings are formidable and merit further consideration.

Current Theories of Aging and Implicit Learning

The theories of aging discussed above attempt to explain the declines in task performance associated with age by emphasizing the overriding effects of a single general factor. Salthouse has tirelessly promoted cognitive slowing, while others have argued that factors such as working memory or de-differentiation should be considered as primary agents in age-related variance. Regardless of their respective general aging factor, the researchers' agenda is clear; they are attempting to show that a breakdown in a single mechanism (or perhaps a few mechanisms) leads to global processing deficits. Therefore, it should not be surprising that the aging theorists investigating implicit learning conclude that the general factors responsible for deficits in explicit processing mediate the observed declines in implicit functioning. The findings are employed as a justification for arguing against the view that the implicit system is biologically and functionally distinct from the explicit system. The researchers overlook evidence of the dissociation of the implicit and explicit systems, possibly because of the assumption that

all brain functions are influenced by the same general aging factors, be they cognitive slowing, working memory deficits, or de-differentiation. This view is laid out clearly by Salthouse et al. (1999) with the assertion:

> "It appears that implicit learning... can be measured reliably at the level of individuals, and that it exhibits relatively small age-related effects. However, it does not appear to reflect a qualitatively different type of processing than that involved in other variables because the smaller age relations appear to be attributable to weaker relations of the implicit variables to whatever it is that many cognitive variables have in common" (p. 17).

Salthouse et al. (1999) argue that implicit learning exhibits less age-related decay than other cognitive processes, not because implicit learning is dissociable from other cognitive systems, rather, the factors causing cognitive deficits do not have a major impact on implicit learning.

However, with some basic theoretical probing, the conclusions of Salthouse et al. (1999) becomes quite dubious. If implicit learning is not a "qualitatively different type of processing", then why is it that they seem to show "weaker relations... to whatever it is that many cognitive variables have in common?" As mentioned above, there is a wealth of neurological findings demonstrating that the implicit and explicit system are separate and rely upon different neurological mechanisms, yet there is no mention of these findings by either Hoyer and Lincourt (1998) or Salthouse et al. in their discussions of implicit learning and aging. In order for their theory to gain authority they must account for the neurological findings supporting the separate systems view. At close inspection, it is evident that support for the systems view is covertly embedded in their discussions of aging and implicit learning. Salthouse et al. readily acknowledge that implicit learning is not as affected by age as are other processes. Similarly, many of the results reported by

Hoyer and Lincourt suggest that implicit processes show less age-related decline than explicit processes (Howard & Howard, 1989, 1992; Meulemans et al., 1996).

Much like Salthouse et al. (1999), Hoyer and Lincourt (1998) posit that the deficits arising in implicit learning tasks (Cherry & Stadler, 1995; Frensch & Miner, 1994; Howard & Howard, 1997) are caused by the same factors that lead to deficits in explicit tasks. Therefore, age-related deficits in processing speed and other mechanisms such as chunking, associative learning, and/or instance based learning, are thought to contribute to age-related variance in explicit and implicit tasks. Once again, the evidence for existence of two neurologically distinct systems is ignored.

To date, a majority of the studies on the elderly (though there are admittedly too few studies to confidently draw global conclusions) consistently demonstrate less age-related variance on implicit tasks. Despite these findings, the view that general factors must impact all processing takes precedence over the notion of separate processing systems in theory construction.

Theories of Aging and Implicit Learning Unite!

Perhaps, the notion that a general aging factor is responsible for the vast majority of age-related cognitive declines can be utilized in the formulation of a theory of aging that maintains the dissociation of the implicit and explicit systems. Although, as Salthouse et al. (1999) concluded, implicit learning is not as affected by age as other forms of learning, the results exhibit a trend where small age-related differences are often observed in implicit task performance. These differences are usually not as pronounced as the deficits found with explicit tasks, however, there is increasing evidence for the belief that small, but reliable differences arise in some implicit tasks. The differences

tend to appear in the more complex tasks such as the dual task SRT (Frensch & Miner, 1994), or an SRT task that employs high order (third and fourth degree) contingencies (Howard & Howard, 1997). It is possible, and even probable in light of the preliminary empirical findings, that internal factors such as working memory and processing speed are responsible for some of the age-related variance observed on implicit tasks. As mentioned earlier, Frensch and Miner found age-related deficits in a dual task SRT experiment. They concluded that short-term memory capacity is the likely culprit and other findings have also suggested that working memory processes may impact implicit learning performance (P. J. Reber & Kotovsky, 1997). Hoyer and Lincourt (1998) note that processing speed and several other primitive associative mechanisms are likely to affect implicit functioning. However, because the implicit and explicit systems show some overlap in processing, in that both may be somewhat dependent on working memory and processing speed, these observations do not in any way dictate that implicit and explicit processes must be pieces of the same processing pie. Internal factors including working memory and processing speed may exert influence over both systems, but they are likely to affect the two systems differently, leading to larger age-related declines in explicit than implicit task performance. As Salthouse et al. (1999) conclude, "the smaller age relations [observed with implicit learning tasks] appear to be attributable to weaker relations of the implicit variables to whatever it is that many cognitive variables have in common" (p.17).

The conflicting research goals of implicit learning and aging theorists has prohibited the two fields from synthesizing a theory of aging which integrates what is known about implicit learning phenomenon with what has been ascertained regarding the

cognitive declines associated with aging. This discordance occurs despite the fact that the findings from the two areas often point in the same direction. Both areas consistently obtain evidence that implicit processes are relatively age resistant, with much of the age-related variance observed in implicit tasks resulting from the use of difficult experimental paradigms, where secondary internal factors are likely to be contributing to the observed age differences. These findings strongly suggest that implicit and explicit processes are dissociated and belong to two distinct systems. The two systems share in some processing overlap, as factors such as working memory and processing speed are likely to affect both systems. However, the dissociation of the implicit and explicit systems remains intact, with the internal factors having weaker relationships with the implicit system. The factors that are thought to contribute to age-related deficiencies in cognitive performance do not appear to have a substantial impact on implicit processes, suggesting that the implicit system is resistant to age-related decay and functions with higher levels of efficiency at the end of the lifespan, when compared to explicit processes.

Pilot Data

A pilot study compared the performance of a small group (n = 10) of older adults (mean age = 77.3 years) taking classes at Brooklyn College with a group (n = 30) of younger Brooklyn College students (M = 19.1 years) on an implicit AG task and an explicit pattern completion task. The findings from the pilot study provided some useful insights in designing future experiments investigating the affects of age on implicit learning. Specifically, the results from the implicit AG task showed that although the elderly subjects required more trials to successfully recall the strings during the learning phase of the task, there were no significant differences during the test phase between the

young and old participants for accuracy in judging grammaticality, response times, and confidence ratings. However, these findings are not convincing in demonstrating that implicit learning is not affected by age as the young participants were more accurate, faster and more confident in their decisions. None of these findings were statistically significant, but the differences in accuracy and response time are at least noteworthy ($p = .14$ and $p = .12$ respectively), especially when considering that there were only 10 elderly participants in the experiment which limits the power of the analysis (see Figures 1 & 2). Further study is needed to determine if there are any meaningful age differences on AG task performance.

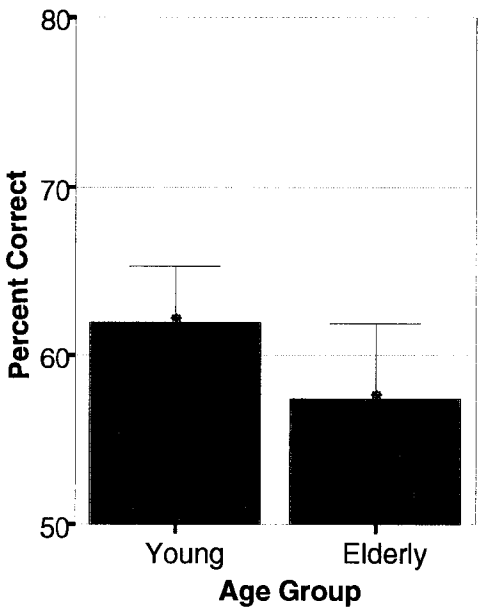

Figure 1. *Mean Percent Correct well-formedness judgments from the pilot study.*

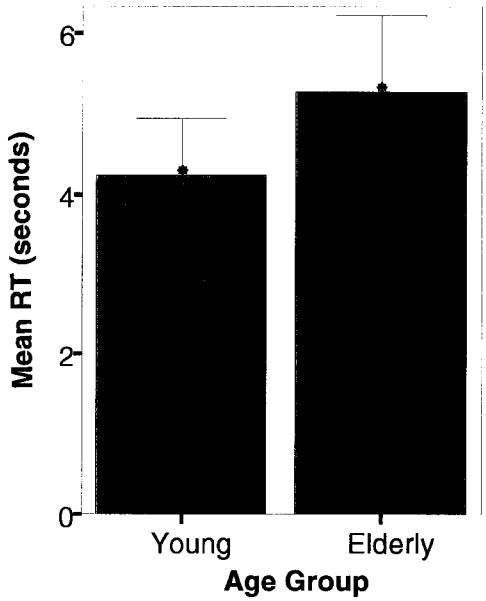

Figure 2. *Mean response times on the AG task from the pilot study.*

The old participants were as accurate as young participants on an explicit pattern completion task, but needed significantly more time to solve the problems (see Figures 3 & 4). Therefore, although there was no age discrepancy in the accuracy of responding there was one in the response times. Based on these findings it seems likely that if both

groups were given less time to respond, the aged group would be more compromised by the time limit. This idea will be pursued further, but it should be stated that time limits generally lead to decreased performance among all subjects in explicit tasks, but they have more of an impact on aged subjects possibly because of cognitive slowing caused by aging (Salthouse, 1991, 1994, 1996).

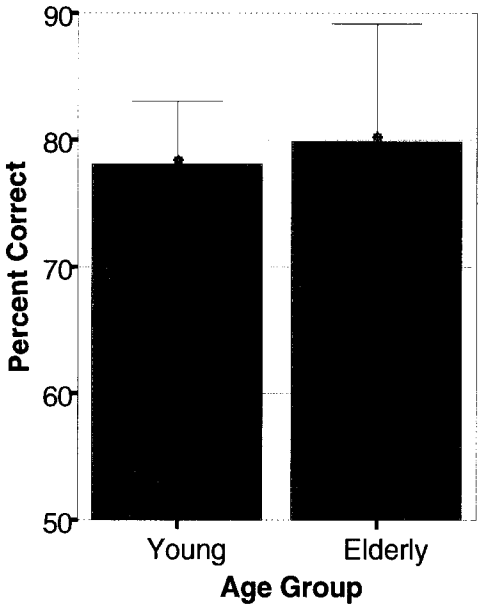

Figure 3. *Mean percent correct on the explicit learning task taken from the pilot study.*

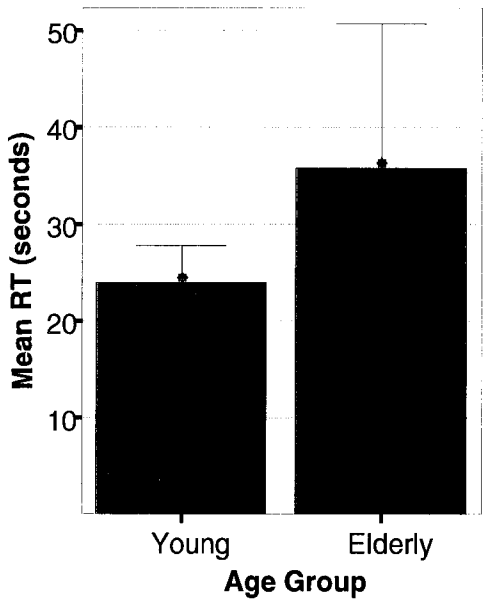

Figure 4. *Mean response times on the explicit learning task taken from the pilot study.*

Extending the Pilot Study

Turner and Fischler (1993) developed an experimental procedure that could assist in elaborating on the effect cognitive slowing has on implicit performance. In their experiments, using the AG learning paradigm college-aged subjects were presented with either an implicit or explicit instruction set. The explicit condition had subjects attempt to discover the rules used to generate the strings during the learning phase while the implicit condition simply had subjects memorize the strings. During the testing phase of the

experiment, both age groups were given long (6 seconds) and short (2 seconds) response deadlines to make the well-formedness judgments. The researchers found that when subjects were working within the implicit instruction set, performance was similar during the long and short response deadlines, while for the explicit rule discovery instruction set, performance was superior during the long response deadline. Turner and Fischler provide no insights as to how age would affect performance on implicit and explicit tasks with response deadlines, but it would be easy to employ this procedure and to compare the performance levels of different age groups. Although this procedure would not provide a direct measure of processing speed, if elderly participants show similar response patterns to the college-aged subjects employed by Turner and Fischler, it would strongly suggest that implicit tasks are less dependent on speed of processing. Moreover, the findings offer another opportunity to compare the implicit learning abilities of old and young adults.

Based on the Turner and Fischer (1993) findings it seems sensible to impose long and short response limits to the explicit task employed in the pilot study described above. The older participants took significantly longer to respond during the explicit pattern completion task suggesting that shorter response limits are likely to create larger accuracy deficits for the older participants. This finding coupled with the expected finding that response limits should not significantly affect performance on the implicit AG task would provide further evidence that for a dissociation between the implicit and explicit systems.

Aging research has been highly effective in recording typical age-related processing deficits, and has attempted to uncover the primary processing sources of these deficits. An understanding of how and why implicit processing mechanisms remain relatively unaffected by age may offer insights in how to improve performance on

cognitive tasks by making the elderly aware of the robustness of their implicit systems. A simple alteration in the instructions in various cognitive tasks can move the task away from the explicit realm and towards the implicit domain, and this can lead to dramatic improvement in task performance. Knowlton et al. (1987) demonstrated a dramatic improvement in performance among amnesics on an AG task when implicit instructions were employed instead of explicit instructions. It is possible that this observation would generalize to elderly populations as well. Therefore, it is plausible that instructing the older individuals to rely on implicit processes whenever possible, while performing a variety of cognitive tasks, could reduce the age-related variance associated with these tasks. At the very least, the findings that implicit processes remain intact can offer a glimmer of light to the otherwise pessimistic nature of aging research. Not everything that is cognitive decays with age. These findings can provide a boost of confidence to the elderly as well as to those attempting to determine how to slow the aging process with behavioral or biological therapies.

The notion that the implicit system is dissociable from the explicit system and acts independently of age provides new directions for new hypotheses and experimental paradigms. The age independence of the implicit system should be put to systematic empirical testing. Studies employing all of the available implicit learning paradigms should be carried out with participants of all ages and all levels of cognitive ability, to determine reliably and definitively how aging influences implicit processes. The existing literature suggests that the age effects would be small and largely produced by internal factors such as working memory and processing speed. This issue requires clarification

and studies investigating the root causes of any age-related variance on implicit tasks should be vigilantly pursued.

Summary

The last decade has provided increasing support for Reber's (1993) view that the explicit and implicit systems are distinct cognitive systems relying on different brain structures and that, unlike the explicit system, the implicit system functions relatively independently of age and developmental level. Nevertheless, there is a reluctance among aging researchers to accept the systems view, due perhaps to a fixation on theories of aging which attempt to identify a general factor as the cause of global cognitive deficits. Salthouse and Hoyer have yet to effectively integrate the existing theories of aging with the findings that implicit tasks consistently yield little or no age-related declines. This lack of a synthesis is regrettable as the findings that implicit processes are relatively resistant to age-related decay, suggests that perhaps, older individuals can compensate for some of their explicit processing deficits by relying on implicit strategies in learning, memory, and problem solving tasks. Only a handful of studies investigating the affects of age on implicit learning have been carried out. Therefore, it remains unclear whether there are no age-related declines in implicit learning tasks or if the declines exist, but are simply smaller than those shown in explicit tasks. Moreover, the effects of internal factors such as working memory, attention, and processing speed on implicit learning processes remain elusive and warrant further study.

The experiments described below attempt to shed some light on many of these issues. Specifically, a comparison of the performance of undergraduate college students on an AG task and a series of other cognitive measures with that of elderly continuing

education students at Brooklyn College was performed. The AG task included two instructional conditions designed to tap into either implicit or explicit functions. This allowed for an assessment of the whether different instructional sets impacts AG learning among the young and old participants. Additionally, the effects of response limits on implicit and explicit task performance were assessed along with WM and processing speed functioning with the goal of uncovering any relationships in function between these internal factors and implicit and explicit task performance. In this context, working memory and processing speed performance can be assessed as possible contributors to any deficits found in either the implicit or explicit tasks.

Chapter 2

Methods

Participants

A sample of older participants were compared with a control group of younger adults.

Older Adults.

Fliers were sent to all members of the Brooklyn College Institute for Retirees in Pursuit of an Education. Thirty one participants aged 65-91 years (M = 75.4) volunteered for the study by responding to the flier. The ages were relatively evenly distributed across the age range (see Table 1). As shown in Table 2, the aged volunteers tended to be highly educated as 45% had graduate degrees. The high level of education was expected because the volunteers were recruited from a college campus organization that offers various courses for the retirees.

Age Range	f	%
65-69	7	23%
70-74	8	26%
75-79	5	16%
80-85	5	16%
85-89	5	16%
90-94	1	3%

Table 1. *Distribution of ages among the old participants.*

Education Level	f	%
High School	5	16%
Some College	2	6%
College Degree	2	6%
Masters	12	39%
Ph.D.	2	6%
Not Available	2	6%

Table 2. *Education levels of the old participants.*

Young adults.

The comparison group consisted of 80 undergraduate students at Brooklyn College volunteering for the experiment in order to fulfill an Introductory Psychology course requirement. Participants between the ages of 17-27 years were included in the

young adults group. The vast majority of young participants were freshmen and sophomores (76.25%) and were under the age of 20 years (72.5%).

The participants in both age groups were volunteers, therefore, the study may have been confounded by selection bias effects. For example, the older volunteers may have been functioning at a higher level than the non-volunteers, and were therefore, more willing to participate in a psychology experiment. Additionally, three of the old volunteers refused to participate in the second session of the experiment. Participant attrition is a common problem in studies requiring multiple test sessions, however the attrition rate was a very manageable 9.7% among the aged participants. Among the young participants 61 of the participants participated in both testing sessions while 19 of the participants only participated in the first session. However, the 19 participants did not drop out of the study, they simply signed up for only one of the testing sessions and were not required to participate in both sessions. Therefore, participant attrition was not a factor among the young participants.

Implicit Task

The implicit task was an AG task. The task is considered implicit because participants tend to show better than chance performance during the testing phase of the task, but demonstrate little or no declarative knowledge of the grammar.

Stimuli.

The stimuli consisted of letter strings ranging from 3 to 8 letters. The strings were presented in the middle of a computer screen in black lettering with a white background and a large 100" font. All of the strings were constructed from the capital letters D, H, M, R, and X. The strings were produced by the finite state grammar shown in schematic

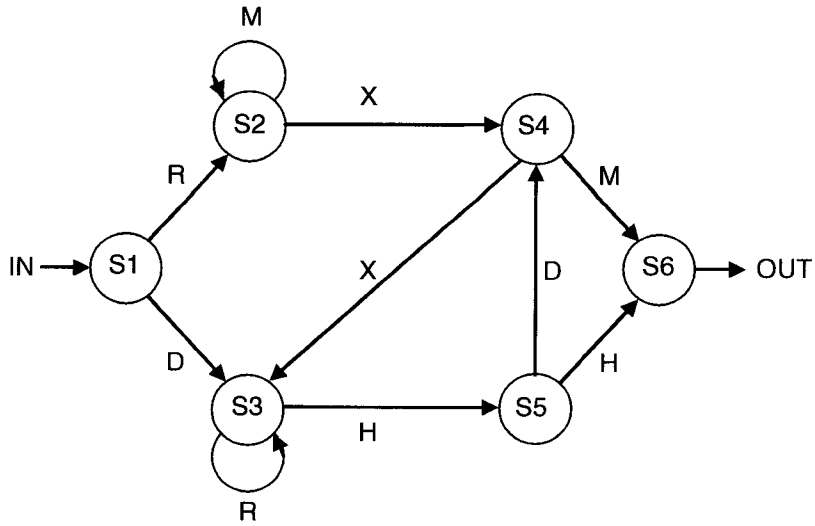

Figure 5. *The artificial grammar used for the implicit learning task (originally used in Reber, 1965).*

Learning Stimuli		Testing Stimuili			
1)	DHDXHDM	*1)	DRRRHDHM	*26)	MHDXRHH
2)	RMMXXHDM	*2)	DHRHH	27)	DHDXRRHH
3)	RMXM	*3)	RMMXXHMM	28)	DRRHDXHH
4)	DHH	*4)	RRHH	^29)	RMXXRHDM
5)	RMMMXXHH	5)	DRRRRHDM	30)	RXXRHH
6)	DRHDXHH	^6)	DHH	31)	RMMMMXM
7)	RXXHDXHH	*7)	DRRDM	*32)	RMXXDH
8)	DRRHH	8)	RXXRRHDM	33)	DRHH
9)	RMXXRHDM	9)	RMXXRRHH	*34)	RXDH
10)	RXXRHDM	*10	DHXDHXDX	*35)	RDRXM
11)	DRHDM	*11)	XXMHR	^36)	DHDXRHDM
12)	RXM	12)	RMMXXRHH	*37)	DRHDXHMD
13)	RMXXRHH	^13)	RXM	^38)	DHDXHH
14)	DHDXRHDM	*14)	RXXHX	39)	DRHDXHDM
15)	RXXRRRHH	*15)	DRRRHR	*40)	MXXHDM
16)	DRRRHDM	16)	RMXXHDM	41)	RXXHH
17)	RMMMXM	17)	DRRRHH	*42)	DHRRRHH
18)	RMMXXHH	*18)	RXH	^43)	RMMXXHDM
19)	DHDXHH	19)	DRRHDM	*44)	DRHHHH
20)	RXXHDM	20)	RXXRRHH	*45)	HMRXHHM
		*21)	DMXM	46)	RMXXHH
		*22)	DRHDDDM	*47)	RXXRHDR
		23)	DRRRRRHH	48)	DHDM
		*24)	RXHDM	*49)	DXDHXHRR
		25)	RMMXM	*50)	HDXRHH

* Indicates a nongrammatical test string.
^ Indicates an Old string that appeared in both the learning and test phases.

Table 3. *Learning and test strings used for the implicit learning task (originally used in Reber, 1965).*

form in Figure 5. A "grammatical" string is created by entering the system at state 1 ("D" or "R") and following the arrows until the system is exited at state 6 ("M" or "X") with the limitation that the string cannot be longer than eight letters. The arrows in Figure 5 define permissible transitions. Forty one different "grammatical" strings were selected for the study. Out of the 41 strings, 20 were selected as learning strings. The remaining 21 grammatical strings were used in the testing phase of the task along with four of the learning phase strings and a set of 25 "nongrammatical" strings. The nongrammatical strings were created by introducing a single violation into an otherwise acceptable string. Table 3 lists all of the grammatical and nongrammatical strings used in the experiment.

Procedure.

The implicit task included three phases: two for acquisition (learning phases) and one during which implicit learning is tested (test phase).

Instruction conditions. There were two instructional conditions within the implicit task. Participants were given either incidental or intentional instructions. The incidental instructions provided little information about the nature of the task and simply told the subjects that they would be presented with a series of letter strings and that their goal was to recall those strings as quickly and as efficiently as possible. Only before the start of the test phase (the last part of the implicit task) were the subjects told that the strings in the learning phase followed certain rules. The incidental instructions attempted to tap into bottom-up implicit processes, since, during the learning phase, participants assumed the task was a memory task and were not made aware of any rule structure (see Appendix A for text).

The intentional instructions (see Appendix A for text) informed the subjects prior to the learning phase that the letter strings they were about to see followed certain rules and that it would be to their advantage to learn as much as they can about those rules. The intentional instructions attempted to tap into explicit functions, since, during the learning phase, participants were encouraged to utilize explicit strategies to figure out the rules of the grammar.

Learning phase. Subjects were initially shown a series of grammatical letter strings (see Table 3) and were asked to copy down each string on a sheet of paper. Twenty learning strings were used and each string was presented twice for a total of 40 learning strings. After copying the strings onto a piece of paper, the subjects were presented with the same letter strings on a computer monitor and were asked to reproduce the strings using the keyboard. In order for subjects to successfully complete this task they were required to correctly reproduce each of the 40 learning strings. Each letter string was presented on the screen for four seconds. After four seconds, the letter string disappeared, and the subjects were expected to reproduce it using the keyboard. Participants were accompanied by an experimenter in an isolated room during the experiment and were permitted to verbally rehearse the strings either silently or aloud before entering them on the keyboard. Some of the elderly participants were assisted in using the keyboard. A subject who correctly reproduced the string with the keyboard was offered positive feedback ("Good Job") and was shown the next letter string to memorize. Once a subject entered an incorrect letter, they were immediately informed about their mistake and shown the string again for 4 seconds. The strings were repeatedly presented (each time for 4 seconds) until the subject correctly reproduced them.

During the pilot study described above, some of the elderly participants struggled to successfully recall the learning strings. Therefore, the copy task was included in the design. By offering more exposure to the learning strings, the copy task was expected to facilitate performance on the recall task for all of the participants, but especially for the older participants. The extra exposure to the learning strings provided by the copy task may also contribute to improved performance during the test phase.

Testing phase. Before beginning the testing phase of the implicit task, subjects who received the intentional set of instructions were reminded that a grammar was used, and subjects who received the incidental instructions were informed that all of the strings that they had just memorized in the memory phase of the experiment followed a complicated set of rules (a grammar). Fifty test strings were used and each test string was presented twice for a total of 100 strings (see Table 3). Subjects were informed that half of the strings follow the rules from the first part of the experiment and half of the strings contain an error. For each test string, participants were required to make a "well-formedness" decision. That is, each participant was required to decide if the test strings were grammatical or not grammatical by pressing the "Y" or "N" keys respectively. All subjects were discouraged from taking too long in making their decision and were given a 6 second (long condition) response limit on half of the trials and a 3 second (short condition) response limit on the remaining half of the trials. The strings remained on the screen until the participants responded and if participants failed to respond within the response limit they were prompted to respond immediately. The order of the response limit conditions was counterbalanced so that half of the participants were in the short response limit condition first while the other half were initially in the long response limit

condition. After each "Y" or "N" response, subjects were asked to indicate how confident they were in their decisions on a confidence scale of 1-3 (1=Not Confident; 2=Some Confidence; 3= Confident), with three being most confident. After each confidence rating the next test string was displayed.

The accuracy and speed of all of the responses were recorded for responses made before (on time) and after (late) the response deadlines. At the end of the implicit task participants were also asked with an open-ended questionnaire if they were aware of any of the rules employed in the AG task and if they had any other general comments about the task.

Explicit Task

The explicit task was a pattern completion problem solving task. The task is considered explicit because it is thought to invite top-down explicit hypothesis testing processes, and participant performance on the task is dependent on whether the participants have acquired explicit knowledge of the patterns.

Stimuli.

The stimuli used in the explicit task were 40 strings ranging in length from eight to 16 letters. Each of the sequences followed a pattern, but several different patterns were employed. For example, a repeating pattern (e.g., ABCABCABC) was used in 10 of the strings, an ascending pattern was employed in 11 of the strings (e.g., ABCBCDCDE), a descending pattern was used in 9 of the strings (e.g., DEFCDEBCD), and a "mixed" pattern (e.g., BEBCDCDCD) was used in 6 of the strings. The strings were presented in the middle of the computer screen in black lettering with a white background and a large

24" font was used. Every effort was made to make the strings easy to read. Table 4 lists all of the letter sequences employed in the explicit task.

The stimuli from the implicit and explicit tasks have superficial similarity in that they are both letter sequences that follow rules. However, the stimuli in the implicit task were used to recruit bottom-up implicit processes while the stimuli in the explicit task were employed to tap into top-down explicit processes.

Incomplete Pattern	Letter Choices		Incomplete Pattern	Letter Choices	
1. TUVSTURSTQR_	T	*S	21. UTSTSRSRQRQ_	*P	S
2. ABCBCDCDE_	E	*D	22. AWXBVWCUVD_	*T	U
3. EFGDEFCDEBC_	*E	D	23. PQRQRSRST_	T	*S
4. BCADECFGE_	*H	G	24. EDCBEDCBEDCB_	*E	A
5. AXBBWCCVD_	*D	B	25. AWAAXAAWAAXAA	*W	X
6. ABCBBCCBCDBC_	*E	B	26. RSTURTSURURURV_	*Q	S
7. PQQPRSSRTVV_	*T	V	27. PDEQCDRBCS_	*A	C
8. PQRSQRSTRSTU_	*S	T	28. FGDEEFCDDEBC_	B	*C
9. BCDEBCDEBCDE_	D	*B	29. TSRQTSRQTSRQ_	*T	P
10. ABXABWABVAB_	V	*U	30. RQPRQPRQP_	*R	Q
11. PQDPQCPQBPQ_	B	*A	31. ABCAABCAABC_	*A	B
12. PQPPQQPQPPQ_	P	*Q	32. PCPPDPPCPPDPP_	*C	D
13. UVSTTURSSTQR_	*R	Q	33. STUTUVRSTUVWQ_	U	*R
14. PQRPPQRPPQRP_	*P	Q	34. ABCABCABC_	B	*A
15. ABCDBCDECDEF_	E	*D	35. QRSTQRSTQRST_	*Q	S
16. ABAABBABAAB_	A	*B	36. ABBACDDCEFF_	*E	F
17. FEDEDCDCBCB_	D	*A	37. CBACBACBA_	B	*C
18. PDQQCRRBS_	Q	*S	38. PQRQQRRQRSQR_	*T	Q
19. CDEFCEDFCFCFCG_	D	*B	39. DEFEFGCDEFGHB_	*C	F
20. QRPSTRUVT_	V	*W	40. PQRPQRPQR_	Q	*P

Alphabetic series (* = correct choice)

Table 4. *Explicit pattern completion task stimuli.*

Procedure.

The explicit task employed 40 letter sequences. Each of the sequences followed a certain pattern (e.g. ABCABCABC__). Subjects were asked to try and determine what

the patterns were and to use that information to decide what letter should be next in the sequence. Participants were offered a choice of two letters for each of the sequences and were asked to choose the letter that correctly completes the pattern. For example, with the letter sequence ABCBCDCDE__ subjects were asked to decide between the letters "F" and "D". The choices were displayed to the right of the letter sequence (see Table 4). Therefore, the example shown above appeared on the screen like this:

ABCBCDCDE__ F or D.

In this case the correct choice would have been "D". Participants were instructed to press the "Z" key if they believed the letter on left hand side was correct and to press the "/" key if they believed that the letter on the right hand side of the screen was correct. Therefore, in this instance the correct response would have been the "/" key. The locations of the correct letter choices were counterbalanced.

After each decision, participants were also asked to give a confidence rating for each of their selections on a scale of 1- 3, with 3 being most confident. After each confidence rating the next letter sequence was presented.

Participants assigned to the "long" condition during the explicit learning task were given 35 seconds to respond before being prompted to respond immediately. All participants assigned to the "short" condition of the explicit task were given 15 seconds to respond before being prompted to respond immediately. Thirty five seconds was chosen as the response limit for the long condition because pilot studies employing this paradigm have shown that the mean response time for older participants on this task is about 35 seconds. The fifteen second response limit for the short condition was selected

because performance did not differ greatly in young participants when 15 seconds was used instead of 35 seconds.

Digit Span and Processing Speed Tasks

The battery of cognitive measures designed to evaluate working memory capacity and the speed of processing included the Digit Span and Backwards Digit Span from the Wechsler Memory Scale III and the digit symbol substitution, from the Wechsler Adult Intelligence Scale Revised. In addition to the pencil and paper tasks listed above a computerized version of the digit-digit and digit-symbol tasks adapted from the processing speed experiments conducted by Salthouse (1992) were administered.

Procedure.

Digit Span and Backward Digit Span. In the digit-span and Backwards digit-span task the experimenter read out a series of numbers. The participants' task was to repeat the numbers. At first participants were given two digits and if the participant succeeded in repeating the two digits with one of two sequences an extra digit was added with up to 9 digits for the Digit Span and 8 digits for the Backwards Digit Span. The Digit Span task required subjects to recall the strings in the order they were presented while the Backwards Digit Span had the subjects repeat the strings in reverse order.

Processing speed tasks. The pencil and paper version of the digit symbol substitution task presented subjects with a table of 9 symbols matched to the numbers 1-9. Below the table was a series of squares filled in with the numbers 1-9 and with an empty square below each number. The participants task was to fill in the appropriate symbol for each number based on the table. Participants were given 90 seconds to complete the task and were told to complete as many of the missing squares as they could

in the 90 seconds. In the computerized version of the processing speed task, participants were presented with a table of the same 9 symbols matched to the numbers 1-9 and were asked to use the table to make same-different decisions about a series of number-symbol pairings. The subjects were also tested for response times by being asked to make same-different judgments based on a series of number-number pairings.

Design and Procedure

There were two sessions for the experiment with each session lasting approximately one hour. All participants performed the AG task during the first session and the explicit task, Digit Span, Backwards Digit Span, and the pencil and paper, and computerized versions of the digit-symbol substitution task during the second session. The order of task presentation was held constant, and two sessions were used to minimize the possible effects of fatigue. After all of the tasks were completed, subjects were asked to complete a short questionnaire used to collect demographic information and any comments about the experiment.

Chapter 3

Results and Discussion

The analyses of the results for this experiment will be presented in four parts. The first three sections will assess performance on the AG task, the explicit pattern completion task, and the Digit Span and processing speed tasks. The final section will analyze the relations between the performance levels on the various tasks with a focus on the relations between performance on the processing speed and Digit Span tasks to AG and explicit task performance.

Implicit Learning Task

Learning Phase.

To determine if there were age group differences in the number of trials required to recall the learning strings, a 2 x 2 ANOVA (Age by Instructions) was conducted. The main effect for age was significant, $F(1,107) = 4.82$, $p = .030$. Figure 6 indicates that older participants required more trials to recall the learning strings ($M = 1.61$, $SE = .058$) than the younger subjects ($M = 1.45$, $SE = .036$). Neither the main effects for instruction ($F(1,107) = 2.34$, $p = .13$) nor the interaction between instruction and age ($F(1,107) = .056$, $p = .85$) were significant. Previous findings from special populations such

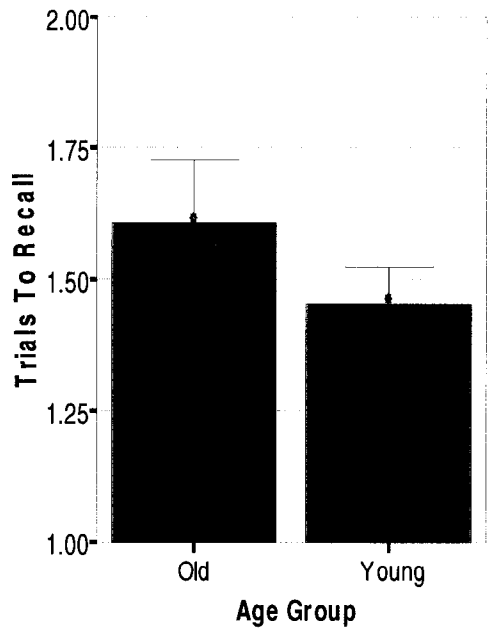

Figure 6. *Mean number of trials needed for young and old participants to recall the Artificial Grammar task learning strings.*

as psychotics (Abrams & Reber, 1989), amnesics (Knowlton, et al., 1990), and highly anxious subjects (Rathus, Reber, Manza, & Kushner, 1994) suggest that this task recruits explicit, top-down functioning. Therefore, the deficits displayed by the aged sample were expected and are probably largely independent of implicit functions.

Testing Phase.

During the Artificial Grammar (AG) task, participants from both age groups were given a short (3 seconds) response limit on half the trials and a long (6 seconds) response limit on the remaining half of the trials. Although the participants were asked to try to respond before the response limit ended, there were some late responses in both age groups. Therefore, in attempting to assess the accuracy of responses, the number of on time and late responses were tallied along with the number of Correct On Time (COT) and Correct Late (CL) responses. The Percentage of Correct (PC) responses across all trials was also calculated. Although PC did not take into account whether responses were on time or late, it offers the most straightforward assessment of success (or failure) in learning the grammar and therefore will open the discussion of the results from the AG test phase. In addition, the Response Times (RT) used to make the well-formedness judgments, and the Confidence Ratings (CR) for each decision were recorded on each trial.

Explicit knowledge of the grammar was also assessed, although less rigorously. At the end of the test phase, all participants were asked to report any rules for the grammar that they remembered. All responses were coded into one of several response categories. Details of this method and the results of the analyses for these responses will be provided later.

This portion of the study utilized a 2 x 2 x 2 mixed model design. The between groups factors were age (young vs. old) and instructions (incidental vs. intentional) and the within groups factor was response limit (short vs. long).

Accuracy of well-formedness judgments. The findings relating to the accuracy of the well-formedness judgments were not anticipated and raised several intriguing questions. The first part of this section will report the results from our analysis with only a limited discussion of the results. A comprehensive discussion of the findings is offered at the end of the section.

Analysis of the PC for well-formedness judgments during the test phase of the AG task revealed significant main effects for age, $F(1,107) = 25.24$, $p < .001$, and instruction, $F(1,107) = 5.55$, $p = .021$. Response limit was the only non significant main effect, $F(1,107) = .51$, $p = .48$. The only significant interaction was between response limit and age, $F(1,107) = 4.51$, $p = .036$.

Single sample t-tests revealed that both age groups performed at levels significantly better than chance (50%) suggesting that both age groups learned (old: $t(30) = 6.30$, $p < .001$; young: $t(79) = 20.31$, $p < .001$). However, as shown in Figure 7, the younger participants ($M = 66.54$, $SE = .82$) were far more accurate when making well-formedness judgments than the older participants ($M = 58.71$, $SE = 1.38$). This finding was unexpected as the majority of studies investigating the effects of age on implicit learning performance demonstrate little or no age deficits.

Figure 8 illustrates that participants in the intentional condition ($M = 66.30$, $SE = 1.09$) of the experiment outperformed participants in the incidental condition ($M = 62.36$, $SE = 1.06$). This finding was true for both old and young participants, as the interaction

between age and instruction was not significant, F(1,107) = .037, p = .85. The intentional instructions were designed to recruit top down, explicit processes while the incidental instructions were utilized to tap into bottom up, implicit processes. Therefore, the fact that the intentional instructions produced higher levels of learning was surprising, particularly for the older participants who were expected to show less benefit from top-down processing.

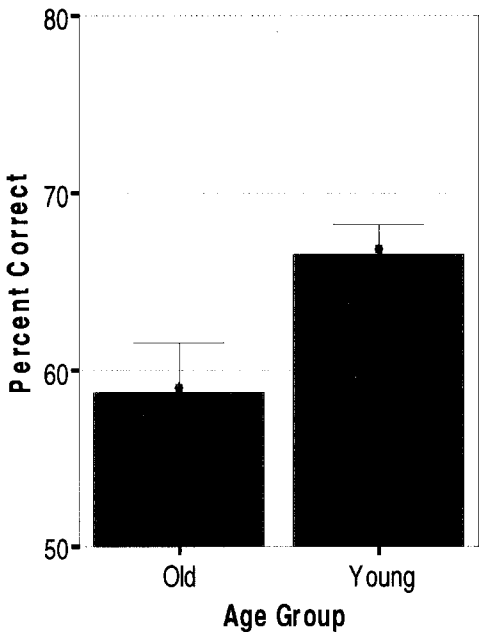

Figure 7. *Mean percent correct for old and young participants on Artificial Grammar well-formedness judgments.*

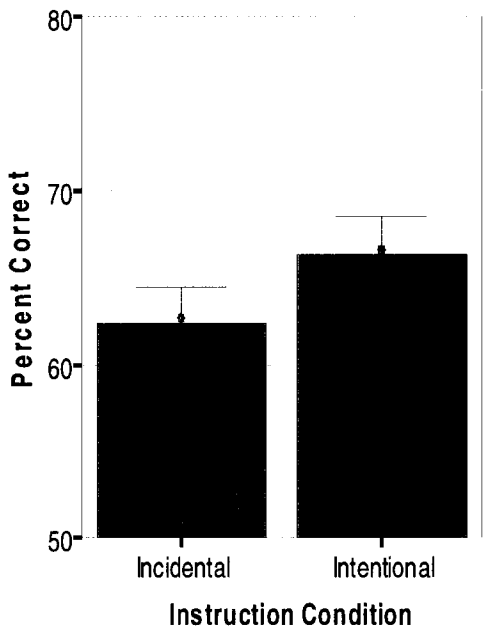

Figure 8. *Mean percent correct Artificial Grammar well-formedness judgments with incidental and intentional instructions.*

As noted earlier, the response limit manipulation did not produce significant differences in PC (p=.47) whereas the age by response limit interaction was significant (p=.036). Figure 9 illustrates the nature of the significant interaction. It is clear from the chart that older participants were more accurate during the short response limit condition while younger participants were slightly more accurate during the long response limit condition. Planned comparisons revealed a significant difference between the response

limit conditions for the old group, t(30) = 1.91, p = .033, but the response limit difference failed to reach significance for the young group, t(79) = 1.27, p = .10.

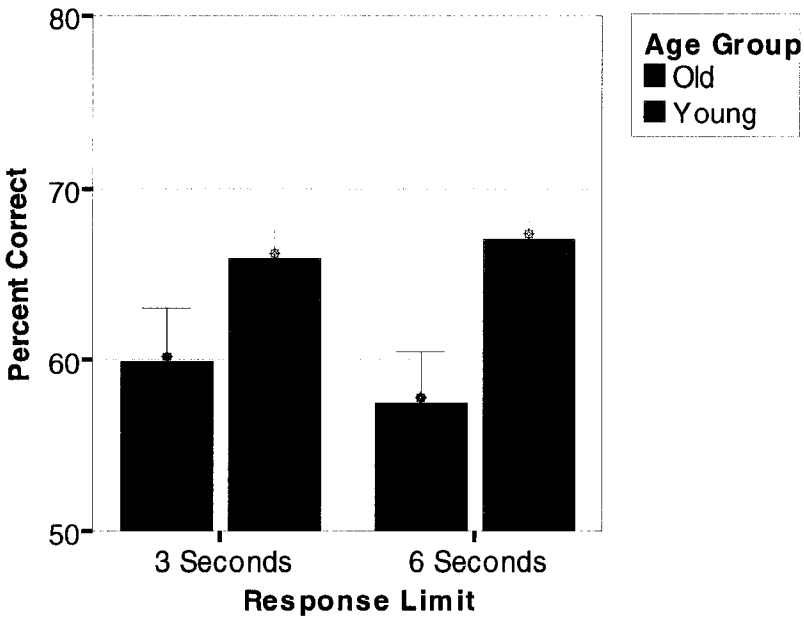

Figure 9. *Mean percent correct for old and young participants during the 3 second and 6 second response limit conditions of the Artificial Grammar task.*

Before summarizing the number of on time, late, Correct On Time (COT), and Correct Late (CL) responses, further analysis of the age by response limit interactions is called for. A post-hoc analyses employing the Speed of Responses (SR) as an additional factor was utilized to probe further into the interplay between the time used to make well-formedness decisions and the accuracy of the decisions.

In an attempt to correct for the fact that some responses were made after the response limits passed, each of the participants' responses were divided into 4 SR quartiles based on their individual Response Times (RT), and the accuracy (PC) of the responses within each SR quartile were compared. The advantage of this procedure is that it corrects for overall individual differences in RT while allowing for a comparison of the accuracy of each subject's fast and slow responses. The intention was to provide insights

into the nature of the age by response limit interaction where older participants were more accurate within the short response limit condition while younger participants showed higher (if not significantly higher) accuracy levels within the long response limit condition. Based on this finding it would be expected that older participants show greater accuracy for the faster SR quartiles, as these responses would be analogous to responses made during the short response limit condition. Meanwhile, the younger participants, who were slightly more accurate during the long response limit condition, would be expected to be slightly more accurate during the slower SR quartiles. These expectancies however, were not borne out by the data.

The data were re-analyzed with SR built in as an additional factor. The 2 x 2 x 2 x 4 (age by instruction by response limit by SR) mixed model ANOVA revealed no meaningful changes in the significance levels for the age, instruction, and response limit main effects, nor for any of the interactions. The main effect of the Speed of Responses (SR) was highly significant, $F(1,107) = 12.95$, $p < .001$. Figure 10 illustrates an inverse relationship between the Speed of Response (SR) and decision accuracy (PC). This finding was evident for both age groups and across both response limit conditions, as the age by SR, $F(1,107) = 1.19$, $p = .314$ and response limit by SR, $F(1,107) = .24$, $p = .857$) interactions were not significant. None of the three and four way interactions reached significant either.

A plausible and compellingly straight forward explanation for the observed relationship between the speed of responses and decision accuracy is that participants took more time to make well-formedness judgments on the more difficult test items, and were therefore, more likely to respond incorrectly. Given this explanation, it is of

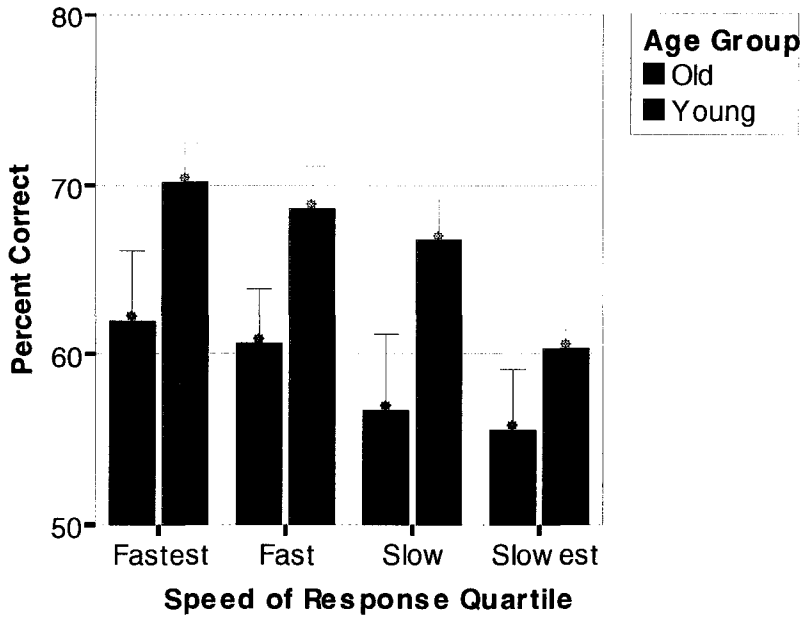

Figure 10. *Mean percent correct for old and young participants within the Speed of Response (SR) quartiles of the Artificial Grammar task.*

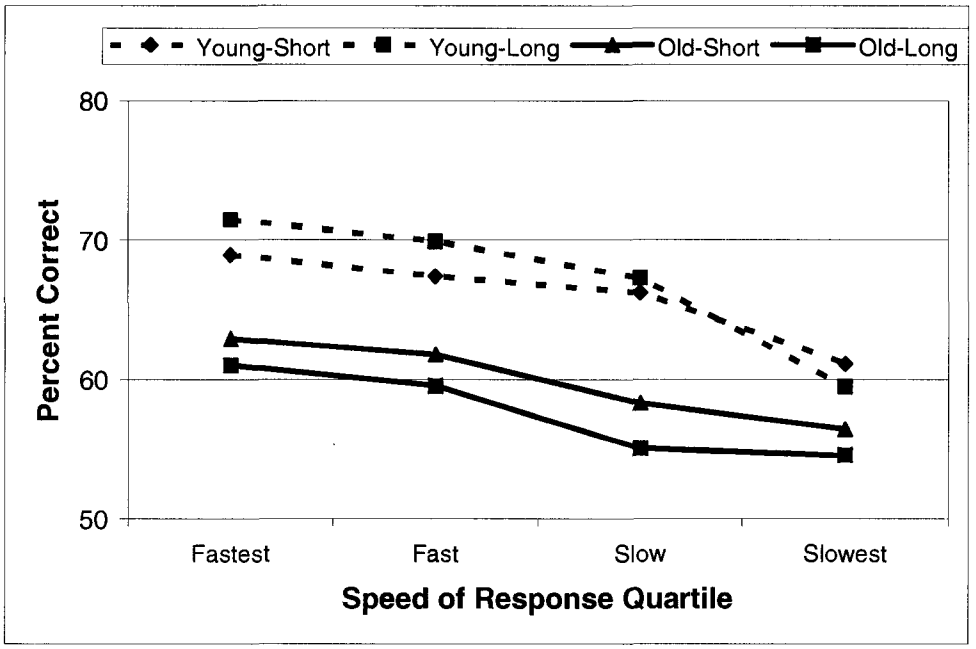

Figure 11. *Mean percent correct on the Artificial Grammar task within each of the Speed of Response quartiles for responses in the short (3 seconds) and long (6 seconds) response limit conditions.*

particular interest that the identical trend is evident in both the short and long response limit conditions. Figure 11 presents the PC's for both age groups in each of the response

limit and Speed of Response (SR) quartiles, and demonstrates that while both age groups were more accurate in the faster SR quartiles, the older participants were more accurate for the short response limit condition within each of the 4 SR quartiles, and the younger participants were more accurate in 3 of the 4 SR quartiles during the long response limit condition. The lack of an age by Speed of Response (SR) interaction indicates that for both young and old participants, slower responses tended to be less accurate. Nonetheless, the significant age by response limit interaction was corroborated within the context of the SR analyses.

These findings suggest that while the slower SR responses in the short response limit condition tended to be less accurate than faster SR responses, they did not differ significantly from the slower SR responses in the long response limit condition. Therefore, although the two response limit conditions affected the accuracy levels (PC) of the old and young groups differently, they did not affect the PC's within the four Speed of Response (SR) quartiles in any meaningful way. It appears as if the response limit manipulation influenced participants' response patterns so that "fast" responses within each response limit condition tended to be more accurate than "slow" responses, despite the fact that what could be considered fast in the long response limit condition would likely be categorized as "slow" in the short response limit condition. This result is both surprising and provocative, but a look at the response times of old and young participants is required before trying to explain the results from the Speed of Response (SR) analyses. The response time results will be summarized later on in this section.

Thus far, the focus has been on three findings: (1) A significant age deficit in the accuracy of responses (see Figure 7), (2) older participants performed better in the short

response limit condition relative to the long response limits, while there was no significant effect of response limit on the accuracy of the well-formedness decisions of the younger participants (Figure 9), and (3) for both age groups faster responses were more accurate than slower responses in both the long and short response limit conditions (Figure 11). The number of on time and late responses along with the number of Correct On Time (COT) and Correct Late (CL) responses will be presented below.

Dependent Variables	Main Effects						Interactions	
	Age		Response Limit		Instructions		Age * Response Limit	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*
On Time	7.76	0.0063	86.62	>.001	0.073	0.79	11.98	>.001
Correct On Time	24.22	>.001	48.39	>.001	1.91	0.17	2.15	0.14559
Correct Late	4.99	0.028	76.40	>.001	0.053	0.82	9.96	0.0021

Table 5. *Results from the series of 2 x 2 x 2 ANOVA's for the artificial grammar task. The factors were age, instructions and response limit and the dependent measures were the number of on time, correct on time, and correct late responses. None of the factors showed significant interactions with the instructions factor for any of the dependent variables therefore, only the age by response limit interaction is presented in the table.*

A series of 2 x 2 x 2 mixed model ANOVA's were performed to assess the effects of age, instructions and response limit on the number of on time, Correct On Time (COT) and Correct Late (CL) responses. Table 5 provides the results for these statistical tests. When the total number of on time responses regardless of accuracy, was employed as the dependent variable, significant main effects were found for age ($p = .0063$) and response limit ($p < .001$). Specifically, the younger subjects were on time more often, and across both age groups there were more on time responses in the long response limit condition. The key finding from this analysis was the significant interaction between age and response limit ($p < .001$). The nature of the interaction is illustrated in Figure 12. The figure clearly shows that during the short response limit condition old participants were

on time less frequently than young participants ($p < .001$), but with the long response limit, the difference in on time (or late) responses was negligible ($p = .26$).

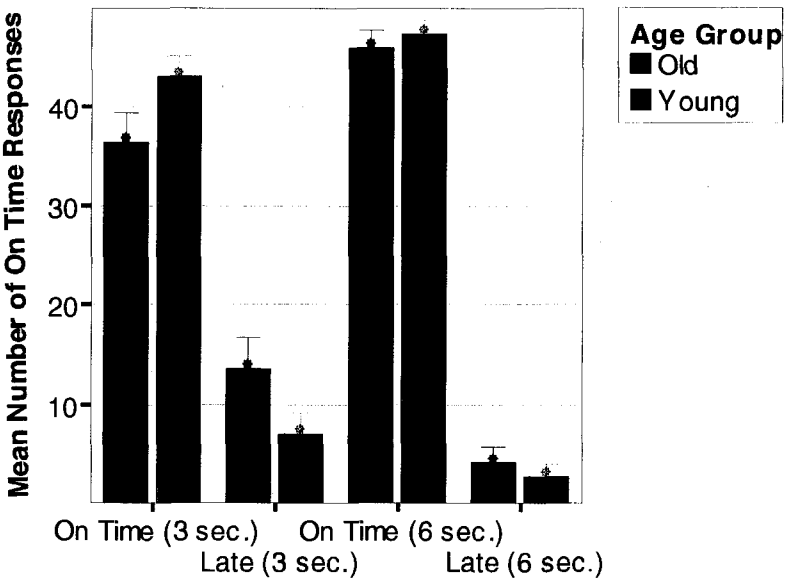

Figure 12. *Mean number of on time and late responses in the short (3 sec.) and long (6 sec.) response limit conditions for old and young participants.*

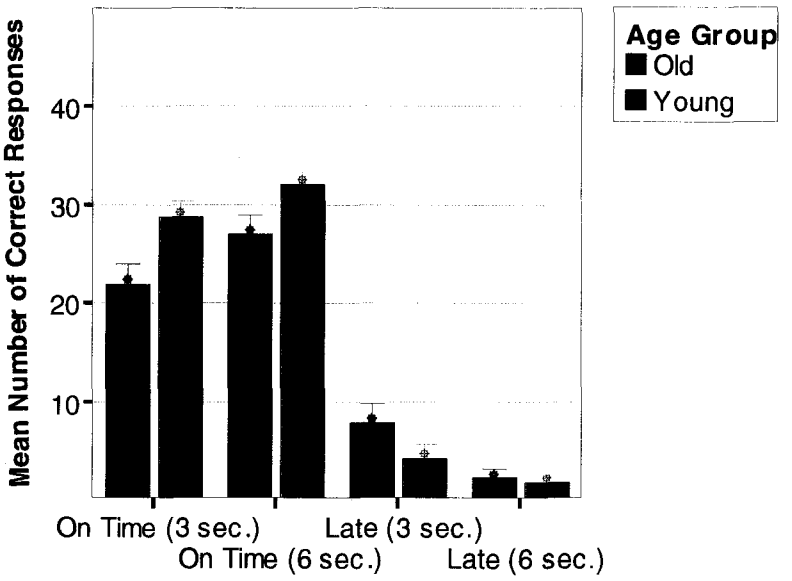

Figure 13. *Mean Number of Correct On Time (COT) and Correct Late (CL) responses in the short (3 sec.) and long (6 sec.) response limit conditions for old and young participants.*

Turning to the number of Correct On Time (COT) responses, once again there was a significant age deficit ($p < .001$), with younger participants producing more COT responses than older participants. The response limit main effect was also significant ($p < .001$) as there were more COT responses in the long response limit condition. However, the age by response limit interaction was not significant with COT employed as the dependent variable ($p = .15$). Figure 13 shows a similar age deficit in the number of Correct On Time (COT) responses in both response limit conditions signifying the lack of an interaction.

The fact that participants were on time and correct on time more often during the long response limit condition can be easily explained by the fact that the long response limit condition allotted more time for a response. Furthermore, because the young participants were accurate on a greater percentage (PC) of their responses and aged populations tend to be slower in responding, the age deficits in the number of on time and Correct On Time (COT) responses were also not surprising. However, given the significant age by response limit interaction with the Percentage of Correct (PC) responses (mentioned earlier in this section) and with the number of on time responses, it is odd that the age by response limit interaction was not significant with the number of Correct On Time (COT) responses employed as the dependent variable. An explanation for this seeming contradiction is offered by the analyses of the number of Correct Late (CL) responses.

When the number of Correct Late (CL) responses was employed as the dependent variable, once again, and not surprisingly, the main effects for age ($p = .028$) and response limit were significant ($p < .001$). Moreover, the age by response limit interaction

returned to significance with CL as the dependent variable ($p = .0021$). Figure 13 presents the CL findings in addition to the COT responses discussed earlier. Far fewer Correct Late (CL) responses were made within both age groups in the long response limit condition. Furthermore, although there was a significant age effect on CL, it was in the opposite direction from the previous effects. That is, the older participants produced a greater number of CL responses than the young participants. The fact that older participants produced a greater number of correct late responses was to be expected given that the old participants were late on significantly more trials. However, the age by response limit interaction with CL as the dependent measure adds another wrinkle to these already untidy finings. The figure indicates that the short response limit condition yielded a substantial age difference in the number of Correct Late (CL) responses with the older participants ($M = 7.90$, $SE = .89$) showing significantly ($p = .0041$) more CL responses than the younger participants ($M = 4.29$, $SE = .67$). However, the age deficit waned dramatically in the long response limit condition ($p = .49$) when the number of total late responses was similar for the two age groups (CL: old: $M = 4.03$, $SE = .79$; young: $M = 2.64$, $SE = .68$).

Careful inspection of the above described results and figures sheds some light on the nature of the response limit by age interaction. To review, older participants were more accurate with their short response limit responses compared to their long response limit responses. However, as noted earlier, the accuracy (PC) measurement did not take into account whether responses occurred before or after the response limits lapsed. When late responses are taken into account, a more complete picture is revealed. As noted earlier, there was no age by response limit interaction with the number of Correct On

Time responses. This lack of an interaction is easily explained by the fact that older participants were late on more of their short response limit responses (see Figure 12) and as a result were correct on fewer on time responses (see Figure 13). Moreover, the older participants were correct on significantly more of their late response in the short response limit condition while there were no differences in the number of late or Correct Late responses in the long response limit condition. Therefore, the age by response limit interaction was evident with PC as the dependent measure of accuracy because the late responses were included in this analysis. However, when the late responses were omitted from the analysis of the number of Correct On Time responses, the age by response limit interaction failed to reach significance.

So far the results present a challenging, yet intriguing set of findings related to the accuracy of the participants' well formedness judgments. All of the results from the AG task will be discussed in detail at the end of this section and will be revisited later on in the context of the results from the explicit learning task and from the processing speed and Digit Span tasks.

Response Time. Inspection of the Response Times (RT) for the old and young participants in making well-formedness judgments revealed a significant main effect for age, $F(1,107) = 11.54$, $p < .001$). Specifically, the old participants were significantly slower than the young participants (see Figure 14). The fact that the older participants were slower in responding was expected as older participants are typically slower in a variety of decision making cognitive tasks. However, the age-related slowing in RT illuminates some of the findings from the analyses of the accuracy of the well-formedness decisions. As noted earlier in this section, when the response times were

broken down into Speed of Response (SR) quartiles, both age groups were less accurate with slower responses and more accurate with faster responses (see Figure 10). Similarly, between the age groups, the young participants who were more accurate with their responses tended to show faster RT's while the old participants tended to be slower and less accurate. Therefore, the age-related slowing in RT allows for the possibility that items categorized as fast for an older participant might have been categorized as slow for a faster young participants.

The main effect for response limit was highly significant, $F(1,107) = 85.52$, $p < .001$). Predictably, the short response limit responses ($M = 2.23$ seconds; $SE = .061$ seconds) were about 750 milliseconds faster than the long response limit responses ($M = 2.99$ seconds, $SE = .091$ seconds) suggesting that the response limit manipulation was effective at influencing the time participants took to respond during the testing phase of the AG task (see Figure 14).

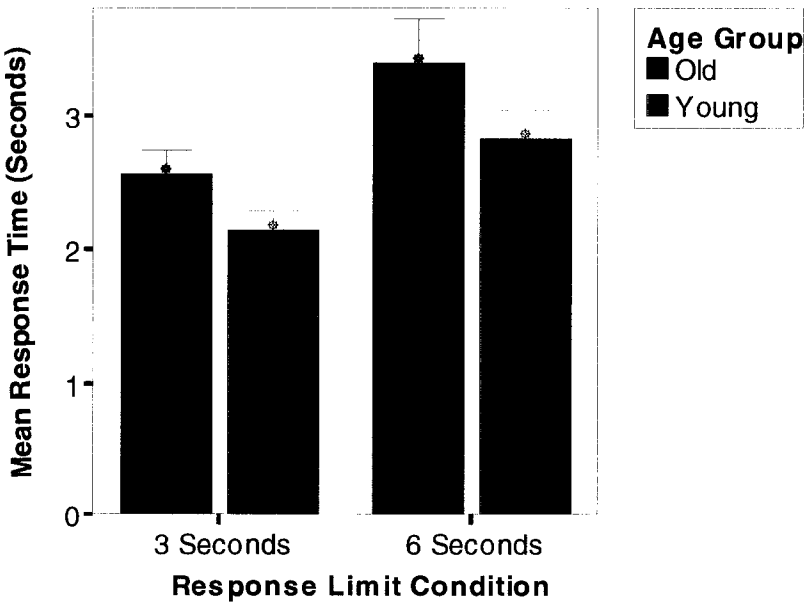

Figure 14. *Mean response times for old and young participants in the 3 second and 6 second response limit conditions.*

The main effect for instruction was not significant, $F(1,107) = .012$, $p = .91$, and there were no significant interactions making the RT findings fairly straightforward. As expected the older participants took longer to make their well-formedness decisions and the response limit manipulations succeeded in producing slower RT's during the long response limit condition and faster RT's during the short response limit condition. The instructional manipulation had no impact on the time participants took to respond.

The implications of the age-related slowing in RT will be discussed further as the issue of speed of processing and its relationship to implicit learning performance, and specifically AG learning performance, will be explored in depth.

Confidence ratings. Following each well-formedness decision, participants were asked to rank their confidence on a 3 point scale (1=Not Confident; 2=Somewhat Confident; 3=Confident). A chi square test for independence revealed a significant difference in Confidence Rating (CR) response patterns among old and young participants, $\chi^2(2, N = 111) = 304.79$, $p<.001$). Figure 15 demonstrates that both young and old participants showed a bias towards confidence in their CR choices, but the older participants clearly showed a stronger bias, as a larger proportion of their CR's were in the confident category. This finding is a bit surprising given that the old participants were less accurate with their responses. Furthermore, Figure 16 shows that for the older participants higher confidence was associated with lower accuracy levels while the young participants were most accurate when they were confident in their responses. A look at the reported knowledge of the grammar makes these findings even more perplexing.

Knowledge of Grammar. At the end of the test phase all participants were asked: "Can you remember any of the rules used to generate grammatical strings?" Responses to

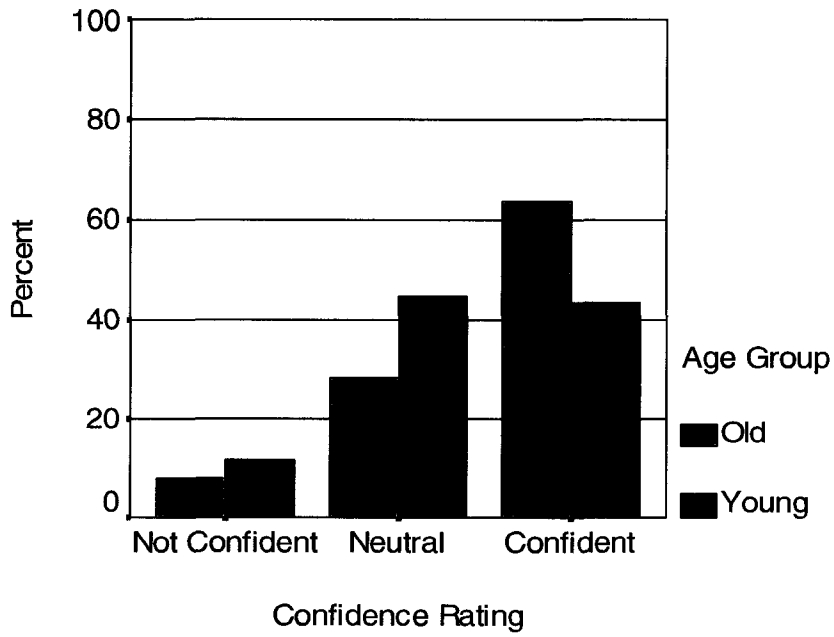

Figure 15. *Distribution of Confidence Ratings (CR) for old and young participants on their well-formedness decisions.*

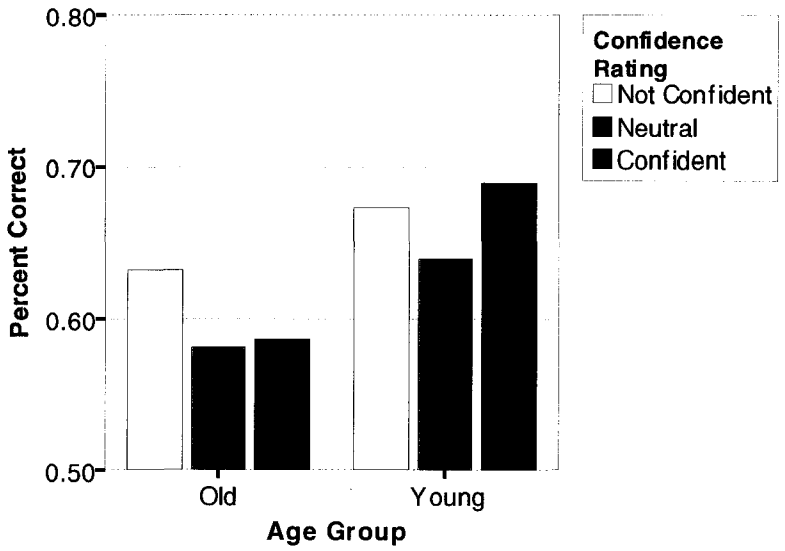

Figure 16. *Accuracy of responses within each Confidence Rating (CR) category for old and young participants.*

this question varied wildly from participant to participant. Many simply said "No", others reported representative rules from the grammar, and still others reported rules or letter

associations that were not part of the Artificial Grammar. The responses of each participant were placed into several categories. Figure 17 presents a breakdown of the responses made by both age groups to the open ended question. All "No" responses were assigned into a category representing no reported knowledge of the grammar (None). All other responses were placed into one of four categories representing either a rule (Beginning Rule, Ending Rule, Repeating Letters, Other) or chunking of letters (Associations) that were representative of the grammar, or into another category representing all rules or letter chunkings that were not representative of the grammar (Bad Rules).

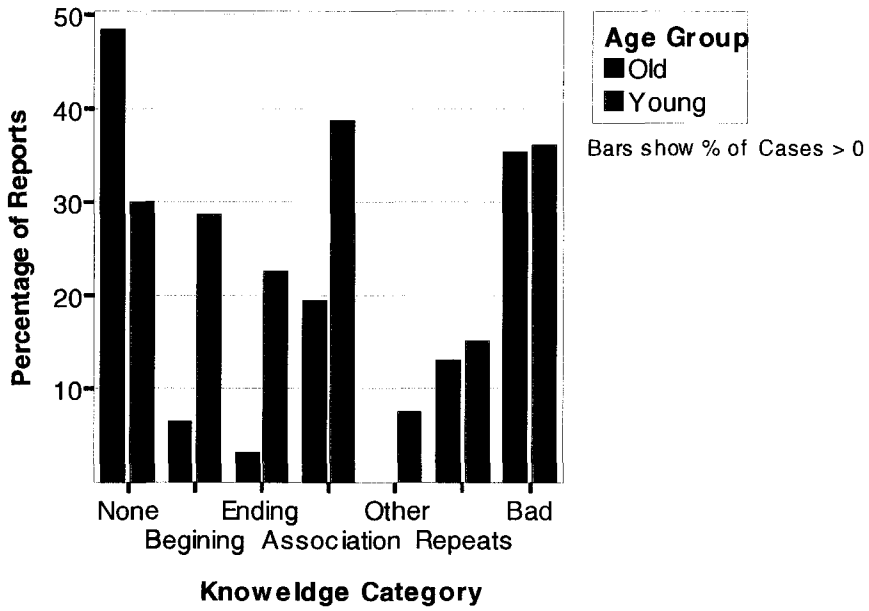

Figure 17. *Percentage of old and young participants who offered responses for each of the knowledge of the grammar categories.*

It is clear from Figure 17 that the older participants were more likely to report no knowledge of the grammar while the younger participants were far more likely to report rules relating to any of the four representative rule categories. In order to allow for direct comparisons of the reported knowledge of the grammar, each individual was given a

knowledge score based on the number of accurate rules or associations reported (accurate rules) subtracted by the number of inaccurate or bad rules reported.

A 2 x 2 between groups multivariate ANOVA was conducted with age group and instruction condition serving as the factors and with the number of accurate rules, bad rules, and knowledge score serving as the dependent variables. The younger participants reported significantly more accurate rules, $F(1,107) = 8.76$, $p = .0037$, and received higher knowledge scores, $F(1,107) = 11.49$, $p < .001$. There was no significant age effect for the number of reported bad rules, $F(1,107) = 1.28$, $p = .26$, but it is still noteworthy that overall the aged group reported, on average, more (if not significantly more) bad rules than the younger group (see Figure 18). It is also telling that the mean knowledge score for the old group, as shown in Figure 18, was actually slightly negative ($M = -.032$, $SE = .22$) while overall, the younger participants showed some knowledge of the grammar ($M = 1.21$, $SE = .21$).

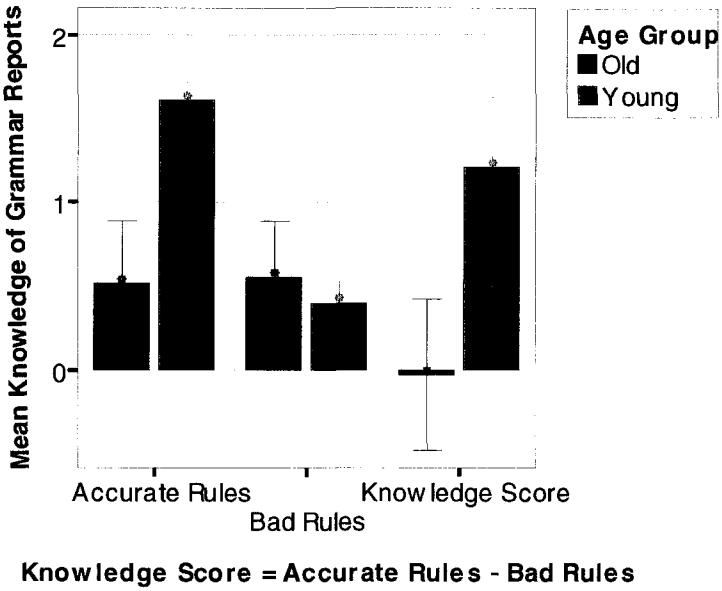

Figure 18. *Mean number of reported accurate rules, bad rules and knowledge scores (accurate rules - bad rules) for old and young participants.*

The main effect of instruction was significant with bad rules as the dependent variable, $F(1,107) = 7.34$, $p = .0076$) and failed to reach significance with accurate rules and knowledge score as dependent variables. Figure 19 shows that overall, there were more bad rules reported with intentional instructions ($M = .61$, $SE = .104$) than with the incidental instructions ($M = .27$, $SE = .071$). However, the bad rules reported during the intentional condition did not lead to reduced accuracy as both age groups were more accurate during the intentional condition. It is possible that these bad rules were not being used during the well-formedness judgments and instead were made up during the questioning.

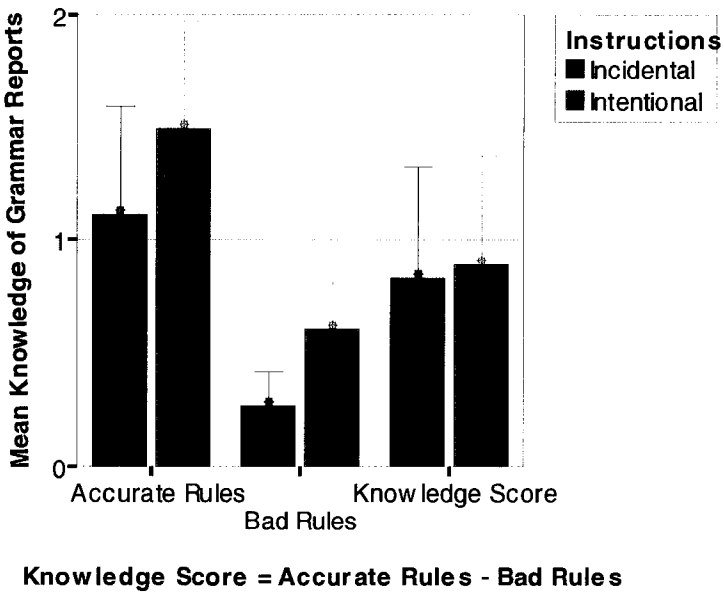

Figure 19. *Mean number of accurate rules, bad rules and knowledge score (accurate rules - bad rules) for the incidental and intentional instruction conditions.*

Pearson correlation coefficients were calculated to shed some more light on the relationship between the reported knowledge of the grammar as assessed by the open ended question at the end of the task and the accuracy of well formedness decisions (PC) during the AG task. For the young participants, the knowledge score showed a significant

positive relationship to the accuracy (PC) of responses on the AG task, r(79) = .35, p = .0017. Furthermore, the number of accurate rules reported showed a slightly stronger and highly significant relationship to PC as well, r(79) = .38, p < .001. However, for the older participants both correlations were substantially weaker and neither reached significance (knowledge score and PC: r(30) = .10, p = .57; accurate rules and PC: r(30)= .18 , p = .34). Table 6 presents all of the correlations between the knowledge of the grammar variables and PC for both age groups.

			Accurate Rules	Bad Rules	Knowledge Score
Old	Percent Correct	*r*	0.38**	0.17	0.35*
		p	<.001	0.13	0.0017
		N	80	80	80
Young	Percent Correct	*r*	0.18	0.051	0.11
		p	0.34	0.78	0.57
		N	31	31	31
** Correlation is significant at the 0.01 level (2-tailed).					

Table 6. *Pearson r correlation coefficients and significance levels for the relationships between reported accurate rules, bad rules, knowledge scores, and the Percent Correct (PC) on the Artificial Grammar (AG) task.*

Explaining the age deficit on the AG task.

Based on Reber's (1993) evolutionary theory of the cognitive unconscious it was proposed that there should be little or no age difference on implicit task performance. Reber's view has received support from various investigations of the effects of age on implicit processes. Therefore, the key finding was that there was a significant age deficit in the accuracy of responses (PC). Although this finding was not expected, it is worth noting that pilot data from the study summarized earlier (see Figure 1) showed a similar, if not statistically significant, age deficit in AG task performance. Furthermore, very few

studies investigating aging and implicit learning performance have employed the AG paradigm.

Although there is good reason to suspect the observed age deficit in AG learning is real, several alternate explanations loom. The data revealed an age-related decline in AG task performance and by extension suggest age-related declines in implicit learning ability. However, the AG task, along with many tasks labeled as implicit, is by no means a process pure task. Both explicit and implicit decision making processes are likely to contribute to AG performance. It is possible, and perhaps likely, that age-related deficits on the explicit components of the task contributed to the age difference. Results from the knowledge of grammar assessments offer some support for this view. The analysis revealed that young participants gained access to some explicit rules and letter associations while the old participants reported little or no knowledge of the grammar (see Figures 14 & 15). Furthermore, significant correlations were found for the young participants between the reported knowledge of the grammar and the accuracy of well-formedness judgments on the AG task, while no such relationships were found for the old participants (see Table 6). These findings suggest that the young participants had greater access to explicit knowledge while performing the task and the level of explicit knowledge may have contributed to their performance on the AG task. On the other hand, old participants showed little or no explicit knowledge of the grammar, and the levels of reported knowledge of the grammar was not related to their performance on the AG task.

The data clearly offer a measure of support for the view that at least a part of the age deficit may be attributable to different levels of access to explicit knowledge among the old and young participants.

There are several other possible explanations for the age deficit in AG learning. Secondary internal factors such as processing speed and working memory, may have played an active role in the age deficits. The digit-symbol and Digit Span tasks were employed as measures of processing speed and working memory span respectively. The results from these tasks as they relate to performance on the AG task will be summarized later in the paper. However, there are several findings from the AG task which suggest that processing speed may have contributed to the observed age deficit in AG learning. As noted earlier, all of the well-formedness responses were placed into one of four Speed of Response (SR) quartiles (fastest, fast, slow, slowest) based on each participants' individual Response Times (RT). The procedure was employed because it corrects for overall individual differences in RT while still allowing for a comparison on the accuracy of each subject's fast and slow responses. Both young and old participants were more accurate with their faster responses than with their slower responses. Due to the post hoc nature of the analysis, it is impossible to determine if the lower accuracy is attributable to the slower responses or if the slower responses are attributable to the lower accuracy. In other words, we cannot determine whether the participants were slower with the more difficult items or if the items became more difficult as participants spent more time trying to make well-formedness decisions.

An important finding regarding the relationship between the speed and accuracy of responses was that the mean RT's of the older participants were significantly slower than those of the younger participants. The SR analyses demonstrated that within each individual, slower responses were less accurate than faster responses. Similarly, the age group difference in RT demonstrates that in addition to being less accurate with their AG

decisions, the older participants generally took longer to make their decisions. A reasonable question to ask than is whether the age difference in the accuracy of the AG decisions (PC) was mediated in any way by the age difference in RT. Perhaps, the older participants were less accurate because they were slower in responding. It is also possible however, that the older participants were slower because they had more difficulty with the task.

An attempt was made to exert some control over the RT's of the participants as response limits were imposed. On half the trials a 3 second (short) response limit was used and the remaining trials included a 6 second (long) response limit. One of the more provocative findings was the significant age by response limit interaction with the long response limit condition producing significantly poorer AG task performance for the old participants, and marginally better performance among the younger participants (see Figure 9). While noteworthy on its own, the age by response limit interaction is enhanced by the fact that, overall, the younger participants were faster at making their well-formedness decisions. In general rapid responses are associated with a mixture of implicit and explicit processing while more deliberative response times are thought to often recruit explicit processes. While tentative, a simple interpretation of this pattern of results is that the longer response limits tapped into explicit decision making processes that were compromised by age-related deterioration.

However, because the age by response limit interaction was evident across both instructional conditions, and both age groups performed better with intentional instructions designed to tap into explicit processes (see Figure 8), the findings are quite puzzling. Nonetheless these results do at the very least suggest that response limits have

differing effects on young and old participants with the AG task. This finding, when considered in the context of some of our previously noted results, becomes especially relevant (e.g., Turner & Fischler, 1993).

Summary.

So far the data for the AG task have produced a murky empirical landscape with several surprising findings. However, a number of results converge to suggest that while an age deficit was found in AG task performance, at least part of that age deficit is likely attributable to explicit processes. Specifically, aged participants reported far less knowledge of the grammar and were less accurate when given more time to make decisions with a longer response limit. The two findings taken together suggest that older people had less access to explicit knowledge for the grammar and were at a disadvantage when given more time to deliberate on their well-formedness decisions, perhaps because the longer response limit often recruited top down, explicit decision making processes.

Interpretation of the confidence rating data.

Another issue pertinent to the age deficit in AG performance is raised by the confidence participants had in their responses. Many of the old participants objected to the nature of the task. Specifically, they were uncomfortable with the notion that while they were informed that there was a grammar used to generate the grammatical strings, they were unable to determine the grammatical rules. In other words, they were uncomfortable with the implicit nature of the task. Perhaps the discomfort of not having explicit knowledge of the grammar contributed to performance anxiety among our highly inquisitive aged sample (all were volunteers), which in turn could have interfered with implicit learning decision making processes. Although this last point is highly speculative

it merits further investigation as many aged participants expressed discomfort with the implicit task while the vast majority of younger participants expressed no objections to the AG task.

We now return to the puzzling Confidence Rating (CR) findings. An obvious question arises: If the aged were less accurate with their responses, were often uncomfortable with the task because of their lack of knowledge, and reported less knowledge of the grammar, why did they show a strong bias towards greater CR's? One possible explanation is that the aged participants were experiencing cognitive dissonance. That is, they were told of a grammar, were often unable to figure out what the grammar was, and were then asked to make well-formedness judgments based on the grammar. Therefore, because the older participants were more uncomfortable with this situation, when they were forced to make CR judgments they may have compensated by developing a false sense of confidence. Perhaps they used rules that while not consistent with the grammar, provided some structure to the task, which served to alleviate the dissonance. Several participants reported employing strange rules for making well-formedness decisions. For example, one older participant reported saying "Yes" to all test strings which they felt would be easy to memorize and "No" to all of the more difficult strings. More qualitative data relating to this issue is obviously required before any firm conclusion on this topic can be reached and it should be noted that the dissonance may have stemmed from a lack of implicit knowledge as well. In other words perhaps the quirky response patterns arose because their intuitions offered no hints in how to respond. That said, it is interesting that the aged participants showed the highest accuracy when they were the least confident (PC = 63.2) while the young participants were the most

accurate when they were the most confident (PC = 68.6) in their responses (see Figure 16). This finding is very much in line with the previously reported result that the knowledge score showed a positive and significant relationship to the Percentage of Correct (PC) responses for the younger participants, but the same relationship failed to reach significance for the older participants. Therefore, the lack of a relationship between reported knowledge and actual performance on the AG task for the aged participants along with the finding that the aged participants were most accurate when they were least confident provides a measure of support for the view that the aged CR ratings were influenced by a form of cognitive dissonance. This explanation of the CR response patterns of the aged participants is similar to other findings showing that older participants tend to either deemphasize negative stimuli or to be less effective in processing negative stimuli than they are with positive stimuli (Charles, Mather, & Carstensen, 2003). Proponents of the socioemotional selectivity theory (Carstenson & Charles, 1998) argue that older people actively emphasize positive stimuli and deemphasize negative stimuli to maintain a healthy emotional state.

Some challenging results.

Several curious results remain that merit further discussion. One such result was that participants in the intentional instruction condition were significantly more accurate in making well-formedness decisions than participants in the incidental instruction condition. As noted earlier, the intentional instructions were employed to recruit top-down explicit processing, as all participants in this condition were informed that a grammar was used to generate all of the learning strings at the very beginning of the task. The incidental instructions were designed to rely more heavily on bottom-up implicit

processes as participants in this condition were told about the grammar after they had completed the learning phase and immediately before testing. The finding that participants in the intentional condition were more accurate than participants in the incidental condition was surprising in its own right. However, even more surprising, was that both old and young participants were more accurate with the intentional conditions. Not only was this unexpected, but also challenges the notion that explicit processes may have contributed to the age deficit in AG learning.

Another puzzling result was that when the Speed of Response (SR) quartiles were built into the design investigating the accuracy of responses (PC), age had no relevance to the accuracy of responses in the SR quartiles. Figure 10 shows that older participants were more accurate with the short response limit responses while younger participants were slightly (if not significantly) more accurate with the long response limit responses. Based on these results it was anticipated that the older participants would be more accurate with their faster responses while the young participants would be more accurate with their slower responses. Instead both groups were found to be less accurate with slower responses. The Speed of Response (SR) analysis is further muddled by the fact that old participants were significantly slower with their responses, as fast responses by a slower old participant may have been categorized as slow if they were made by a young participant. We are therefore left with contradictory SR and response limit findings and the data from the present study offer no clear path towards a resolution.

Explicit Learning Pattern Completion Task

Measures for accuracy, Response Time (RT), and Confidence Ratings (CR) were recorded on each trial. The experiment employed age (old vs. young) and response limit

(short vs. long) as factors. Unlike the AG task where response limit was manipulated within groups, for the explicit pattern completion task each subject was randomly assigned to either the short (15 seconds) or long (35 seconds) response limit conditions. Therefore, the study utilized a 2 x 2 between groups design with age (old vs. young) and response limit (short vs. long) as the factors.

Response accuracy.

Although the participants were asked to try to respond before the response limits ended, there were late responses in all of the conditions. Therefore, in attempting to assess the accuracy of responses three different measures were used. The first measure was the Percentage of Correct (PC) responses across all trials. The second measure was the number of Correct On Time (COT) responses, and the third was the number of Correct Late (CL) responses. The number of on time responses was also tallied for both response limit conditions.

		Main Effect				Interaction	
		Age		RL		Age * RL	
		F	p	F	p	F	p
Dependent Variables	Percent Correct	6.57*	0.012	1.23	0.27	0.37	0.55
	On Time	11.53*	0.0010	39.49**	p<.001	6.43*	0.013
	Correct On Time	12.10**	p<.001	27.27**	p<.001	0.14	0.71
	Correct Late	1.16	0.29	28.16**	p<.001	1.69	0.20
* significant at the .05 level (2-tailed) ** significant at the .01 level (2-tailed)							

Table 7. *Results from the 2 x 2 MANOVA for the explicit pattern completion task. Age and response limit were the factors and the dependent measures were Percent Correct (PC), and the number of on time, Correct On Time (COT), and Correct Late (CL) responses.*

A 2 x 2 between groups multivariate ANOVA was conducted to assess the affects of age and response limit on the three measures of accuracy and the number of on time responses. Table 7 presents the results from the MANOVA. The main effect of age was significant with PC (p=.012), number of on time responses (p=.0010), and COT

(p=.00080) as dependent variables and failed to reach significance with CL as the dependent variable (p=.29).

There has been a great deal of research dedicated to examining the performance of elderly populations in various explicit tasks. The general finding has been that aged participants show deficits in explicit learning and memory tasks and are significantly slower at completing these tasks (Salthouse, 1991, 1996; Craik & Salthouse, 2000). Therefore, it was expected that the aged group would show a diminished ability to solve these problems and a general slowing in their response times. It was also expected that for both age groups, participants in the long response limit condition would be correct for more items than participants in the short response limit condition. Furthermore, the short response limit condition was expected to produce a more substantial age deficit than the long response limit condition as the older participants were expected to require more time to solve the problems.

As predicted there was an age deficit on the accuracy of responses for the explicit task. The young participants were significantly more accurate with their responses (see Figure 20), were on time for more responses, and correct on significantly more items before the response limits lapsed (see Figure 21). Like with the AG task, despite the fact that old participants were late for significantly more responses, the difference between the age groups on the number of correct late responses was negligible (see Figure 21).

As shown in Table 7, the main effect of response limit on PC was not significant (p=.27), but highly significant response limit effects were found with the number of on time responses ($p < .001$), COT ($p < .001$) and CL ($p < .001$). Thus, the response limit conditions did not differ significantly on the overall percentage of correct responses (PC),

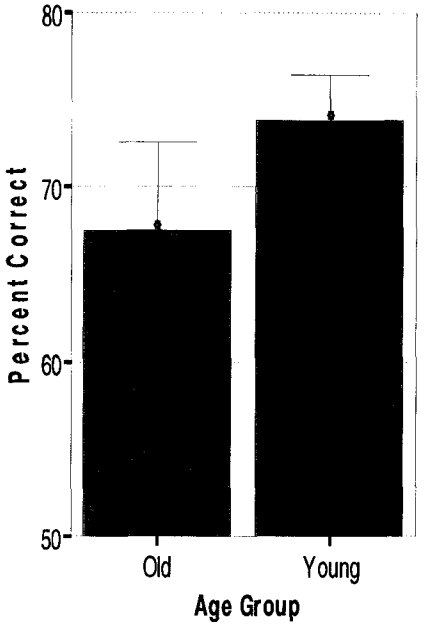

Figure 20. Mean Percent Correct (PC) for the old and young participants on the explicit task.

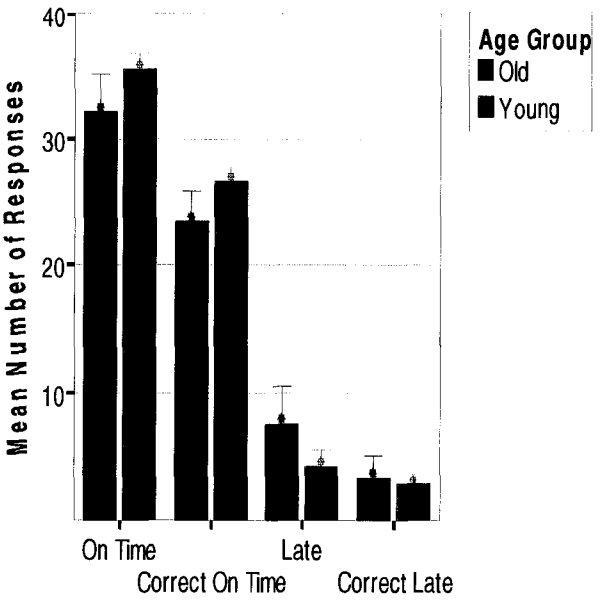

Figure 21. Mean number of on time, Correct On Time (COT), late, and Correct Late (CL) responses for Old and Young participants on the explicit task.

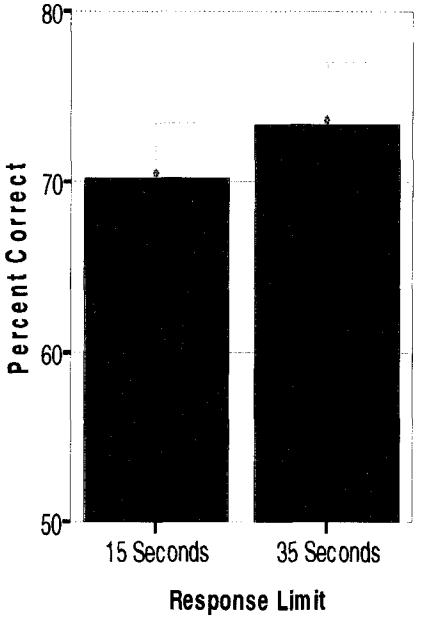

Figure 22. Mean Percent Correct for the short and long response limit conditions of the explicit task.

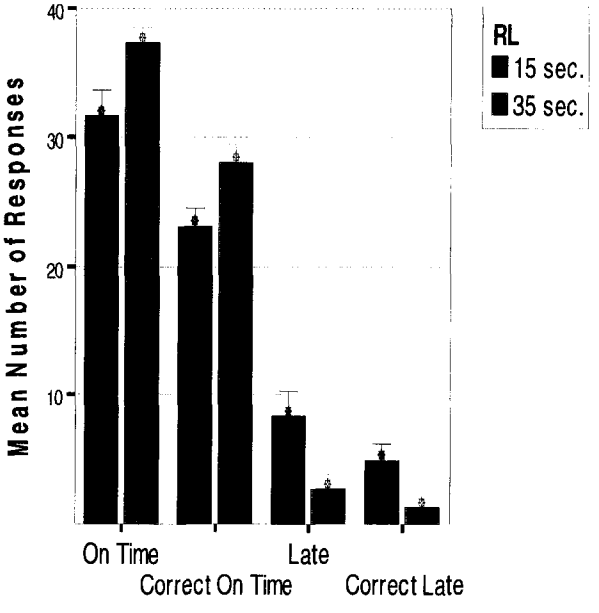

Figure 23. Mean number of on time, correct on time, late, and correct late responses for the short and long response limit conditions of the explicit task.

but, there were significantly more on time and Correct On Time (COT) responses, and fewer Correct Late (CL) responses in the long response limit condition (see Figures 22 and 23). The fact that participants in the long response limit condition were correct for more items before the response limits terminated suggests that, as expected, these participants benefited from the extra time allotted to them in the explicit task.

The hypothesis that the older participants would show a larger age deficit in the short response limit condition compared to the long response limit condition was not supported by the analyses, as the age by response limit interaction did not reach significance for any of the three dependent measures of accuracy (see Table 7: PC: $p = .55$; COT: $p = .71$; CL: $p = .20$). There was, however, a significant age by response limit interaction with the number of on time responses as the dependent variable. Figure 24 demonstrates that while the young participants were on time far more frequently in the short response limit condition, the difference in the number of on time responses was much smaller in the long response limit condition. Therefore, it seems that even though the aged participants were on time with roughly the same amount of responses during the long response limit condition, an age deficit in the number of correct responses in this condition was still evident (see Figure 25). The older participants were more accurate with a longer response limit, but the increase in correct responses was similar in both age groups.

The findings so far are fairly straightforward. An age deficit in explicit task performance was expected and found. Participants in the long response limit condition were expected to outperform participants in the short response limit condition and this was substantiated by their higher number of Correct On Time (COT) responses.

However, contrary to what was predicted, the old participants were correct on fewer items in both the long and short response limit conditions and thus, did not benefit more from the long response limit than the younger participants.

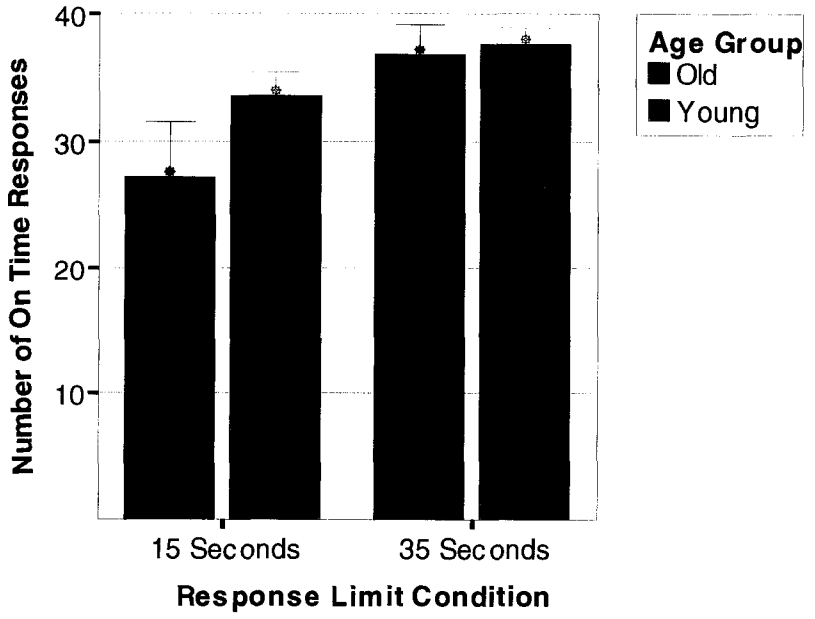

Figure 24. *Mean number of on time responses for old and young participants in the short and long RL conditions of the explicit pattern completion task.*

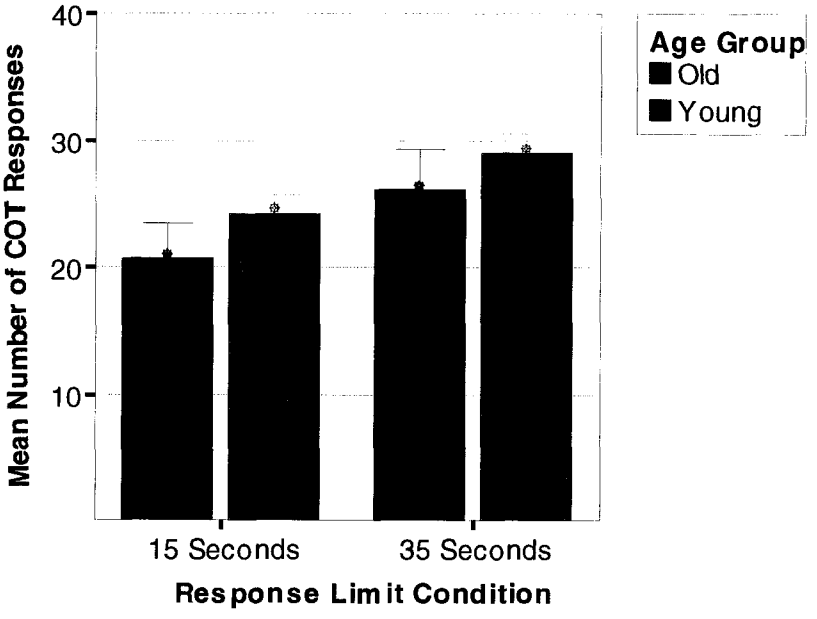

Figure 25. *Mean number of Correct On Time (COT) responses for old and young participants in the short and long response limit conditions of the explicit task.*

When analyzing performance on the implicit Artificial Grammar (AG) task, a post hoc comparison of the accuracy levels for the fast and slow responses was performed. For the sake of consistency, a similar procedure was used with the explicit pattern completion task. Once again all responses were categorized into one of four Speed of Response (SR) quartiles and the accuracy of responses within each quartile were compared.

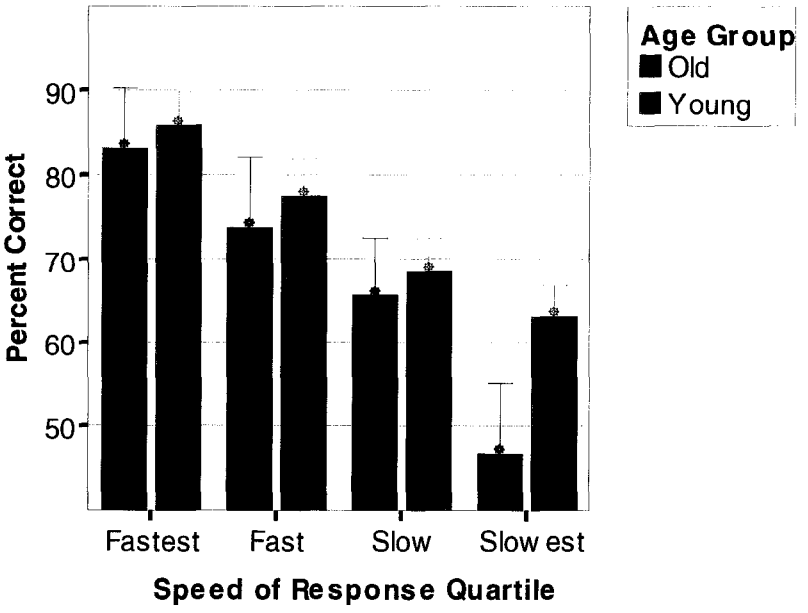

Figure 26. *Percent Correct (PC) for old and young participants within the SR quartiles during the explicit pattern completion task.*

The data were re-analyzed with SR built in as an additional factor. The 2 x 2 x 4 (age by response limit by SR) mixed model ANOVA (SR was the sole within groups factor) revealed no meaningful changes in the significance levels for the age and response limit main effects, nor for any of the interactions. The main effect for the Speed of Responses (SR) was once again highly significant, $F(1,85) = 123.75$, $p < .001$. The results of this SR analyses were somewhat similar to the SR results from the AG task. In both tasks, slower responses tended to be less accurate. However, the AG analysis produced no significant interactions, while analysis of the explicit task revealed a

significant age by SR interaction, $F(1,85) = 3.82$, $p = .011$. Figure 26 illustrates that while both groups were less accurate with slower responses, the aged group showed a more dramatic decline in PC with their slowest responses.

Once again, the relationship between the speed and accuracy of responses is exactly the opposite of a typical speed-accuracy tradeoff. In most explicit tasks, longer response times are associated with higher levels of accuracy, but for both the AG and explicit pattern completion task, slower responses were actually less accurate. The most likely explanation for this result in the explicit task is that participants took significantly longer to respond during the more difficult trials. The task was designed with many patterns that were relatively easy to solve, others that were a bit more challenging, and still others that were very challenging given the time limits. The high accuracy levels with the fastest responses (old: $M = 83.21$; young: $M = 86.00$) suggest that participants gained explicit knowledge of the easier patterns and were therefore, very accurate with these responses. However, with the more difficult items, participants in both age groups required more time and were less accurate. Therefore the items in the slowest Speed of Response (SR) quartile are likely to represent the most challenging items for each subject. Interestingly, while the younger participants performed fairly well with the items in the slowest quartile ($M = 63.17$), the old participants performed essentially at chance ($M = 46.79$; Chance = 50).

An age by Speed of Response (SR) interaction was predicted for the AG task, as larger age deficits were anticipated among the older participants for their slower responses. This was not found with the AG task, but was found in the explicit pattern completion task where there were no such expectancies. However, it seems likely that the

age by SR interaction for the explicit task occurred because of a ceiling effect, as the older participants were unable to solve some of the more difficult items within the time limit, while the young participants were fairly accurate within all of the SR quartiles. Therefore, while the age by SR interaction found in the explicit task was contrary to what was expected, it tenders a fairly straightforward explanation.

Response Time.

A 2 x 2 between groups ANOVA was conducted to assess the Response Time (RT) differences between the age (old vs. young) and response limit (short vs. long) conditions. The main effects of age, $F(1,84) = 4.09$, $p = .048$, and response limit, $F(1,84) = 14.00$, $p < .001$), were both significant while the age by response limit interaction failed to reach significance, $F(1,84) = .50$, $p = .48$. As noted earlier, a general slowing in RT was anticipated from the older group as were longer RT's in the long response limit condition. Figure 27 demonstrates that the old participants ($M = 15.22$ seconds, $SE = 953$ seconds) were significantly slower to respond than the young participants ($M = 12.95$ seconds, $SE = .067$ seconds). It is also clear from the figure that both age groups were faster to respond in the long response limit condition.

The interpretation of the RT results is relatively straightforward. The aging literature has demonstrated that older populations are slower on a variety of tasks and the explicit pattern completion task was no different as the aged participants were significantly slower with their responses in both the short and long response limit conditions. The response limit manipulation was employed to exert some control over the Response Times (RT) of the participants and the significant response limit effect demonstrates that the response limit manipulation was successful in this regard.

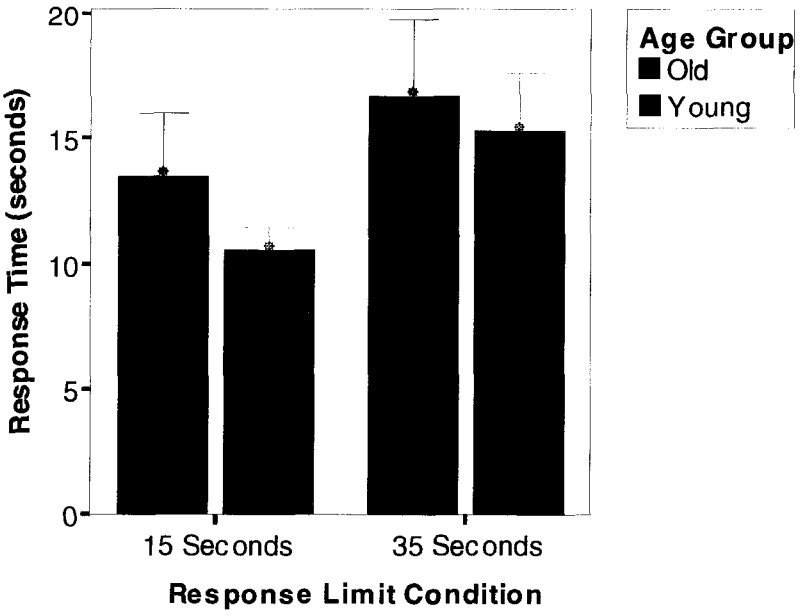

Figure 27. *Mean Response Times (RT) for old and young participants in the short (15 seconds) and long (35 seconds) response limit conditions of the explicit pattern completion task.*

It is worth noting that, as in the AG task, the fact that the old participants showed significantly slower RT's than the younger participants confounds the previously described analyses where the accuracy of responses from the Speed of Response (SR) quartiles were compared. The SR analyses showed that for both age groups, slower responses were less accurate than fast responses, and that this finding was especially true among the older participants. However, because the old participants were slower in RT it is likely that many of the items categorized as fast for older participants would have been considered slower had they been made by a younger participants. This complicates the age by SR comparisons a bit. Nonetheless, the findings from the SR analyses offer some key insights and raise some important questions regarding the relationship between the speed and accuracy of responses among old and young participants in explicit and implicit paradigms.

Confidence ratings.

Following each decision during the explicit pattern completion task, participants were asked to rank their confidence on a three point scale (1=Not Confident; 2=Somewhat Confident; 3=Confident). A chi square test of independence was performed to analyze if participants were biased in their responses and/or to determine if there were any age group differences in the CR response patterns. Results from the chi square test were significant, $\chi^2(2, N = 88) = 6.31$, $p = .043$. It is clear from Figure 28 that both young and old participants showed a very similar bias towards confidence in their CR choices.

Both age groups were more accurate with the responses that they were most confident in. However, the older participants were below chance (.50) for responses for which they lacked confidence (M = .45), slightly above chance for trials they were somewhat confident with (M = .56), and well above chance (M = .82) for the responses which they were confident in. Meanwhile, the young participants were slightly above chance for the responses they showed no confidence in (M = .55), and were well above chance for items they were somewhat confident with (M = .66), in addition to the responses they were confident (M = .84) in. Therefore, while for both groups, increased confidence was associated with increased accuracy, older participants were only slightly above chance for the items where they were somewhat confident, while young participants were well above chance (see Figure 29).

In the implicit task, the CR decisions of both age groups were not clearly associated with the accuracy of responses. This was especially true for the older participants who showed a stronger bias towards confidence than the younger participants, but were most accurate with the responses that they were least confident in

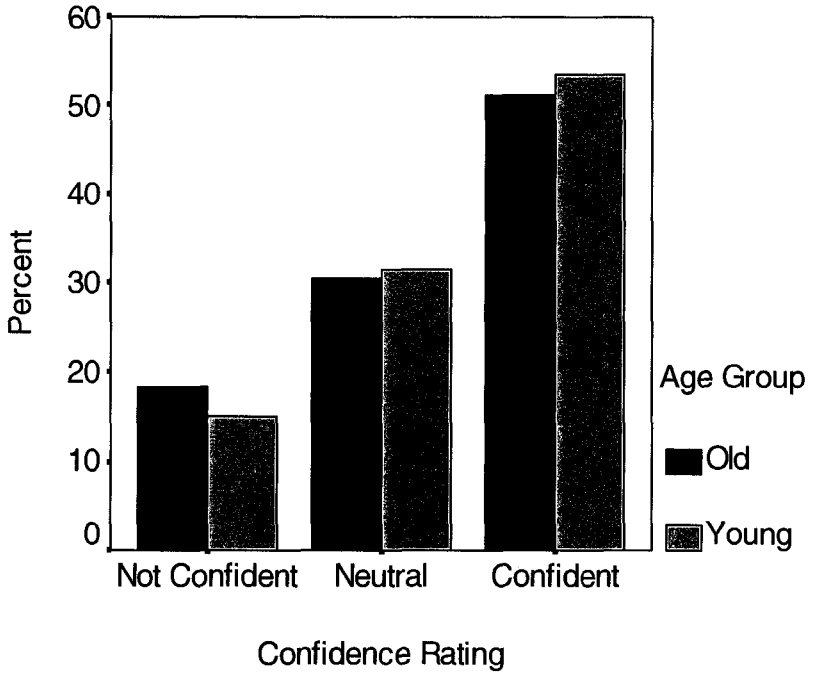

Figure 28. *Distribution of the Confidence Ratings (CR) of the old and young participants on the explicit pattern completion task.*

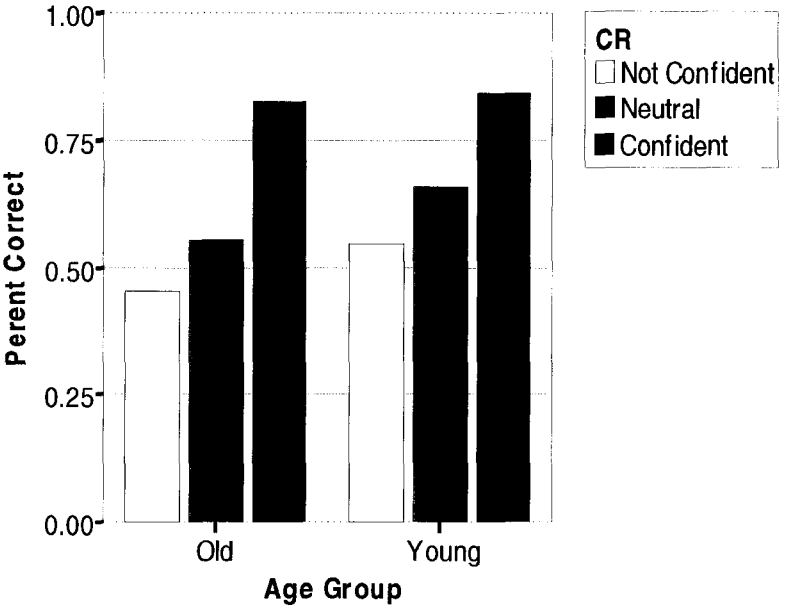

Figure 29. *Percent Correct (PC) within each Confidence Rating (CR) category for old and young participants in the explicit pattern completion task.*

(see Figure 16). These findings suggest that participants in both age groups, but especially in the older group, were unable to predict their own success on the AG task and provides some support for the view that the AG task taps into implicit processes. The fact that the younger participants' responses were somewhat predictive of success on the task (see Figure 16) suggests, however, that there may have been an explicit component to the AG task as well. The knowledge of grammar results described earlier provides further support for this view. On this task the Confidence Rating (CR) data clearly suggest that participants' confidence levels were somewhat predictive of their actual performance suggesting that participants in both age groups had a pretty good idea of when they figured out the pattern, and when they were just guessing. Therefore, for both age groups, the CR findings point towards explicit processing in progressing through the pattern completion task.

It should also be noted that although many of the older participants found the explicit task challenging (some found it overwhelming), none were agitated by the nature of the task. During the implicit task many of the participants were frustrated by their lack of explicit knowledge of the artificial grammar, but in the pattern completion task, the participants may have found some of the items challenging, but they all realized that most of the patterns were accessible and were therefore, not as put off by the task. Perhaps that is why for the explicit task the CR's were better predictors of performance than on the AG task. It was hypothesized that during the AG task, the old group may have experienced cognitive dissonance when making their confidence ratings. Whether the dissonance theory is valid or not, the CR data for the explicit task are clearly more straightforward.

Working Memory Measures

The Digit Span and Backward Digit Span tasks from the WAIS-R were employed as measures of Working Memory (WM). The Digit Span tasks yielded three memory scores: 1) Forward Digit Span, 2) Backward Digit Span, and 3) Total Digit Span which was the sum of the Forward and Backward Digit Span scores. It is worth noting that the Backward Digit Span score is the measure most associated with working memory functions while the Forward Digit Span score is more a measure of short term memory span.

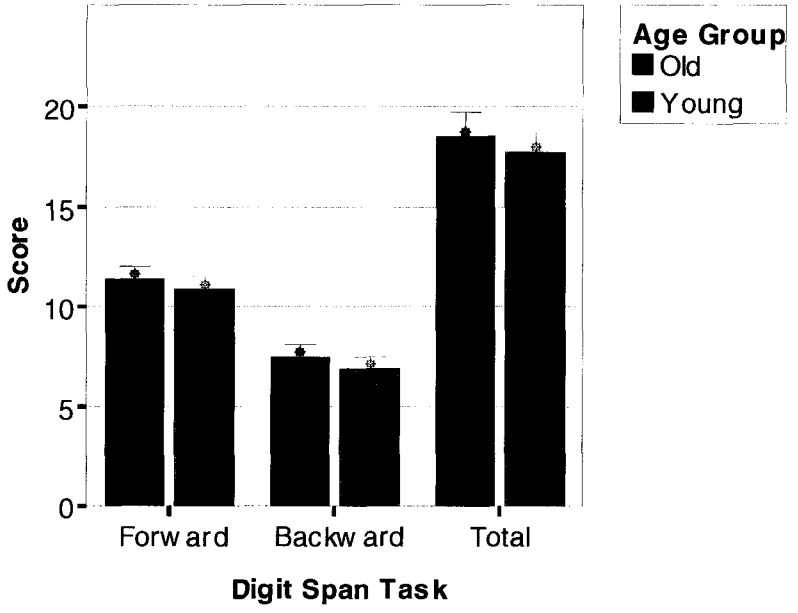

Figure 30. *Forward, backward, and Total digit span scores for participants in the old and young age groups.*

The older participants actually scored slightly higher in all three memory measures (see Figure 30), but none of the differences were significant (Forward: $t(74.65) = 1.27$, $p = .21$; Backward: $t(87) = 1.19$, $p = .24$; total: $t(87) = .91$, $p = .37$). The fact that there were no age deficits on the Digit Span task make it seem unlikely that the age deficit found on the AG and explicit pattern completion tasks were rooted in WM

deficits. However, it remains possible that the variation in performance on the AG and pattern completion task may be associated with the variation of scores on the Digit Span tasks.

Performance on the Forward and Backward Digit Span tasks were significantly, but weakly, related to each other, which is typical of these tasks, r(87) = .29, p=.005. A series of additional Pearson correlations were performed to determine if any of the Digit Span tasks were associated with AG learning or explicit task performance. Due to the fact that our age groups consisted of young (ages 17-27) and old (ages 65-91) participants and included no participants between the ages of 28 and 64, correlations were performed with the combined age groups and separately for each age group. Many variables were included in the correlational analysis. In this section, only correlations of special theoretical interest, or significant correlations that were greater than .3 will be discussed. The r = .3 threshold was selected to avoid Type I errors in interpretation. It can be assumed that all correlation coefficients not reported in this section were either not significant or below the r = .3 threshold.

		Digit Span Tasks					
		Forward		**Backward**		**Total**	
		r	*p*	*r*	*p*	*r*	*p*
AG Measures	Percent Correct	-0.092	0.39	-0.060	0.58	-0.071	0.51
	Response Time	-0.013	0.91	0.17	0.11	0.094	0.38
	Knowledge Score	0.015	0.89	0.15	0.17	0.11	0.30
Explicit Measures	Percent Correct	-0.19	0.075	0.10	0.33	-0.039	0.72
	Response Time	-0.013	0.90	-0.055	0.61	-0.042	0.70

Table 8. *Correlation coefficients and significance levels for the relations between the Digit Span, Artificial Grammar (AG) learning, and explicit learning measures. Note that none of the relationships were significant.*

The variables of note for this stage of analyses were forward, backward, and total Digit Span scores, and the speed (RT) and accuracy (PC) of the AG test phase and explicit pattern completion task responses. When the two age groups were combined in calculating the correlation coefficient, no significant relationships were found among these variables (see Table 8).

When the correlation coefficients were calculated with the older age group, two significant correlations were found. Backward Digit Span was significantly associated with the Percentage of Correct (PC) responses on the AG task, $r(26) = -.44$, $p = .020$) and showed a marginally significant relationship to PC in the explicit pattern completion task, $r(26) = .34$, $p = .078$). As mentioned earlier, the Backward Digit Span task is often employed as a measure of working memory and there is sound evidence that WM may contribute to age-related variance on a host of explicit task paradigms (Salthouse, 1991; Verhaegan & Salthouse, 1997). Although failing to reach significance, the marginally significant relationship between Backward Digit Span performance and PC on the explicit task is still noteworthy as the old group was a very small sample ($n = 22$), and the correlation was fairly strong ($r = .34$), and in the expected direction based on previous research. Therefore, the significant positive relationship to explicit task performance suggests that, among the older participants WM may have contributed to success on the task. The negative relationship between Backward Digit Span performance and AG learning is another matter. This relationship suggests that the worse participants performed on the Backward Digit Span task, the better their performance was on the AG task. Although it has been posited that implicit learning performance should not correlate well with IQ and other cognitive variables (Reber, Walkenfeld, & Hernstadt, 1992) few

theorists would be bold enough to predict a negative relationship between these functions and AG learning. By default, it should be assumed the relationship is simply an artifact of this particular study and would likely fail to replicate. However, if the finding is replicated in the future, theorists would then be required to accommodate this unanticipated result.

			Digit Span Tasks					
			Forward		Backward		Total	
			r	*p*	*r*	*p*	*r*	*p*
Old	AG Measures	Percent Correct	-0.079	0.69	-0.44*	0.020	-0.260	0.18
		Response Time	0.20	0.31	-0.14	0.47	0.077	0.70
		Knowledge Score	-0.22	0.25	-0.10	0.61	-0.16	0.42
	Explicit Measures	Percent Correct	0.12	0.53	0.34	0.078	0.23	0.23
		Response Time	0.210	0.29	-0.190	0.34	0.030	0.88
Young	AG Measures	Percent Correct	-0.043	0.74	0.14	0.27	0.060	0.64
		Response Time	-0.10	0.43	0.22	0.090	0.069	0.60
		Knowledge Score	0.11	0.38	0.27*	0.034	0.24	0.063
	Explicit Measures	Percent Correct	-0.29*	0.021	0.06	0.630	-0.14	0.25
		Response Time	-0.120	0.37	-0.050	0.71	-0.100	0.43
* Correlation is significant at the 0.05 level (2-tailed).								

Table 9. *Correlation coefficients and significance levels for the relations between the Digit Span, Artificial Grammar (AG) learning, and explicit learning measures for the old and young groups.*

The correlations for the younger participants are far easier to interpret as none of the relationships between the Digit Span measures and implicit and explicit learning were above the r = .3 threshold (see Table 9). Taken together with the correlations found with the older participants it seems that while WM, as assessed by the Backward Digit Span task, had little to do with explicit and implicit learning among the younger participants, it may have contributed to implicit AG learning and explicit pattern completion task performance among the older participants. However, while it is sensible to conclude that some of the age-related variance observed in the explicit task may have been related to WM, it seems less likely that there is a negative relationship between AG learning and WM among aged participants.

It is important to point out that while we have been using the Backward Digit Span task to estimate WM functioning, our assessments were by no means rigorous. A far more thorough assessment of WM functions would be required in order to make any firm conclusions regarding the relationships between Working Memory (WM) and implicit and/or explicit task performance.

Processing Speed Measures

Two tasks were utilized to assess processing speed. The first task was a pencil and paper version of the Digit Symbol Substitution paradigm taken from the WAIS-R and the second was a computerized version of the task adopted from Salthouse (1992). The dependent measure for the pencil and paper version of the task was simply the number of correct items completed within the 90 second time limit. For the computerized version of the task, participants' accuracy and response times were recorded. Participants completed four blocks in the computerized version of the task. Independent samples t-tests were employed to determine if there were age differences for the scores on the pencil and paper task and the sum mean response times, and accuracy measures from the computer version of the task.

Dramatic age deficits were found in both versions of the task (see Figures 31 & 32). For the pencil and paper version the younger participants completed about 24 more items in 90 seconds, leading to a highly significant age difference on the speed at which participants executed the task, $t(87) = 9.65$, $p < .001$. During the computerized version of the task, the older participants were, on average, more accurate with their responses, but this difference failed to reach significance, $t(87) = 1.63$, $p = .11$. However, the response times in the old group were dramatically slower than for the young participants, $t(87) =$

9.47, $p < .001$. These findings were as expected based on past studies employing the same tasks with similar age groups (Salthouse, 1991, 1994, 1996).

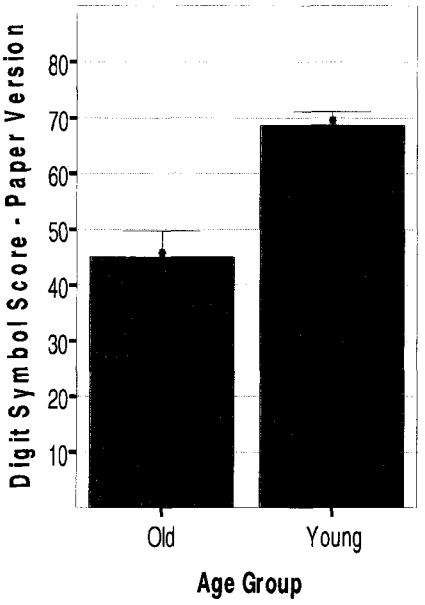

Figure 31. Performance of the old and young participants on the pencil and paper processing speed task.

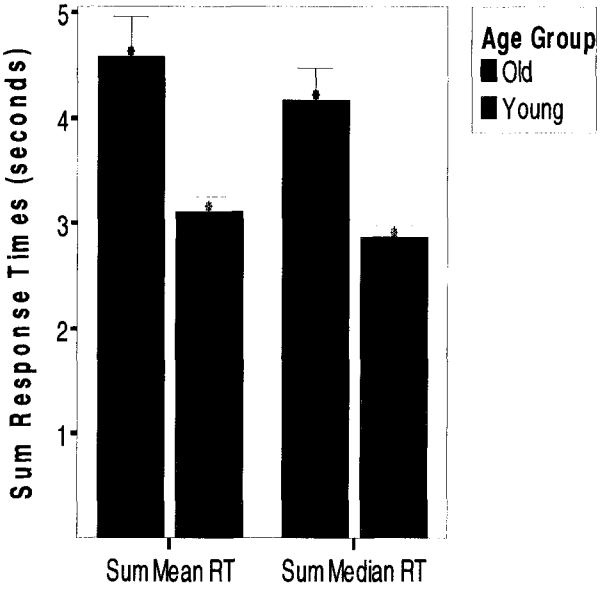

Figure 32. Sum mean and median response times for old and young participants on the computerized processing speed task.

A vast literature exists describing the importance of processing speed in accounting for age-related variance on a wide variety of cognitive tasks (see Salthouse, 1996). The primary purpose of including the processing speed tasks in these experiments was to determine if processing speed, as measured by the two versions of the Digit Symbol Substitution paradigm, was associated in any meaningful way with performance on the AG and/or explicit pattern completion task. It is clear that there were significant age deficits on all of the tasks, but what is unclear is whether the age deficits are somehow related to each other.

It was necessary to exclude all participants who were less than 95% accurate on the computerized version of the digit-symbol task, as is standard with studies employing

the paradigm. Given that the same/different judgments required of participants during the computerized digit-symbol task are simple decisions, it is likely that participants who performed below the 95% threshold were not attending to the task sufficiently. Therefore, two of the aged participants and 8 of the younger participants were excluded.

Once again, in order to avoid Type I errors, only significant relationships stronger than the r = .3 threshold will be discussed in this section. The variables of interest for this phase of the analysis were the scores from the pencil and paper Digit Symbol Substitution task, the sum mean response times on the four blocks of the computerized processing speed task, and the speed (RT) and accuracy (PC) of responses on the AG and explicit pattern completion tasks.

		Processing Speed Measures					
		Paper Task		**Computerized Task**			
		Score		**Sum Mean RT**		**Sum Median RT**	
		r	*p*	*r*	*p*	*r*	*p*
AG Measures	*Percent Correct*	0.30**	0.0043	-0.32**	0.0045	-0.33**	0.0029
	Response Time	-0.29**	0.0058	0.28**	0.014	0.27*	0.016
	Knowledge Score	0.32**	0.0023	-0.38**	<.001	-0.40**	<.001
Explicit Measures	*Percent Correct*	0.31**	0.0034	-0.34**	0.0025	-0.34**	0.0026
	Response Time	-0.14	0.19	0.27*	0.017	0.28*	0.012
* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is sigificant at the .01 level (2-							

Table 10. *Correlation coefficients and significance levels for the relations the processing speed, Artificial Grammar (AG) learning, and explicit learning measures.*

Performance on the pencil and paper version of the Digit Symbol Substitution task showed a fairly strong negative relationship with the sum mean response times from the computerized digit-symbol task, r(86) = -.66, p < .001) as is typical of these tasks (see Salthouse, 1996). Table 10 presents the relationships between the processing speed measures and the dependent measures from the Artificial Grammar task. All of the relationships were significant, and most of them were fairly strong (r >.3). Especially

interesting was the fact that the Percentage of Correct well formedness decisions (PC) showed significant relationships to performance on both processing speed tasks. That is, participants who were slower on the processing speed tasks also tended to be less accurate on the AG task. Furthermore, the knowledge scores which assessed reported explicit knowledge of the artificial grammar were also significantly associated with processing speed as participants with faster processing speed scores tended to exhibit more explicit knowledge of the grammar (see Table 10).

The fact that significant relationships were found between the processing speed measures and AG and explicit task performance is not surprising given the fact that significant age deficits were found in all three tasks. The first step in establishing that processing speed may have contributed to the age deficits in implicit or explicit learning is to establish that the processing speed variables were related to the implicit and explicit task measures independent of the age of the participants. However, because of the substantial gap in the ages of our old and young participants, instead of performing partial correlations with age as a control variable, separate correlations were conducted within each of the age groups.

For the older group, performance on both processing speed tasks were significantly associated with the Percentage of Correct (PC) responses on the explicit pattern completion task (see Table 11). The relationships between PC on the AG task and the processing speed measures were substantially weaker and not close to significant (see Table 11). However, there was a marginally significant relationship of notable strength ($r = -.35$) between the measure of explicit knowledge for the artificial grammar and the speed of responses on the computerized version of the processing speed task (see Table

11). Therefore, among the older participants, who performed significantly poorer on all of the tasks employed in the current study, slower processing speed was associated with poorer explicit learning, and to a lesser, but still noteworthy extent to acquisition of explicit knowledge of the artificial grammar. On the other hand there was no link established among the aged participants between processing speed and implicit learning, as assessed by AG task performance.

			Processing Speed Measures					
			Paper Task		Computerized Task			
			r	*p*	*r*	*p*	*r*	*p*
Old	AG Measures	Percent Correct	-0.19	0.33	0.11	0.62	0.11	0.59
		Response Time	-0.086	0.66	0.28	0.18	0.29	0.16
		Knowledge Score	0.15	0.44	-0.35	0.089	-0.31	0.13
	Explicit Measures	Percent Correct	0.37*	0.050	-0.44*	0.027	-0.44*	0.027
		Response Time	0.019	0.93	0.30	0.15	0.34	0.094
Young	AG Measures	Percent Correct	0.17	0.20	0.026	0.85	-0.007	0.96
		Response Time	-0.17	0.20	0.10	0.49	0.076	0.59
		Knowledge Score	0.16	0.23	-0.14	0.33	-0.20	0.15
	Explicit Measures	Percent Correct	0.036	0.78	0.030	0.83	0.041	0.77
		Response Time	0.0023	0.99	0.19	0.17	0.20	0.14
* Correlation is significant at the 0.05 level (2-tailed).								

Table 11. *Correlation coefficients and significance levels for the relations between the processing speed, Artificial Grammar (AG) learning, and explicit learning measures for the old and young groups.*

The correlations just reported within the aged group raise several intriguing possibilities. The picture with the young participants is very different. There were no significant associations found among any of the processing speed, AG learning, or explicit learning variables.

The fact that significant correlations were found in the old group, but not in the young suggests that processing speed may have impacted performance among the older participants on the explicit pattern completion task, and on their ability to acquire (or

simply to report) explicit knowledge of the artificial grammar. Furthermore, processing speed did not seem to have any impact on any of the implicit or explicit task measures among the younger participants.

The results from processing speed tasks illuminate the previous discussion of the interplay between the speed and accuracy of responses within the AG task. The AG task findings revealed that between age groups and within subjects, slower response times were associated with reduced accuracy. A sensible explanation of the age deficit on the AG task, based on the processing speed and AG data, is that the older participants were unable to acquire sufficient explicit knowledge of the grammar to compete with the younger participants on the AG task. Cognitive slowing associated with old age may have contributed to the aged participants' inability to acquire explicit knowledge of the artificial grammar and this lack of explicit knowledge probably contributed to the lower levels of AG learning among the aged participants.

Was Implicit Learning Performance Related to Explicit Learning Performance?

Although cognitive psychologists have been debating the notion of separate implicit and explicit processing systems for some time, this issue has yet to make a significant impact on theories of aging. Therefore, an analysis investigating whether implicit learning performance was significantly associated with explicit learning performance is of theoretical importance. A lack of a correlation between the accuracy levels (PC) on the AG and explicit pattern completion task would provide additional support for the notion of separate systems while a significant correlation would, at least on the surface, be problematic for the systems view. The correlation between implicit and explicit learning was not significant when both groups were included in the computation,

r(85) = .19, p = .079. However, a noteworthy association was found between explicit learning task performance and explicit acquisition of the artificial grammar, r(85) = .33, p = .0017).

Correlations were also calculated separately for each of the age groups. For the younger participants performance on the explicit learning task was significantly correlated to both AG task performance and explicit knowledge acquisition of the AG. However, these relationships were substantially weaker and not significant with the older participants (see Table 12).

	Combined Age Groups		**Young Only**		**Old Only**	
	Explicit-PC		Explicit-PC		Explicit-PC	
	r	*p*	*r*	*p*	*r*	*p*
Artificial Grammar PC	0.19	0.079	0.33*	0.010	-0.25	0.20
Knowledge Score	0.33**	0.0017	0.31*	0.015	0.22	0.27
* Correlation is significant at the 0.05 level (2-tailed)						
** Correlation is sigificant at the .01 level (2-tailed).						

Table 12. *Correlation coefficients and significance levels for the relations between the Percentage of Correct (PC) responses on the Artificial Grammar (AG) and explicit learning pattern completion tasks. Correlations were calculated for the combined aged groups and separately for old and young age groups.*

To summarize, among the younger participants, explicit learning performance was associated with implicit learning performance and acquisition of explicit knowledge for the artificial grammar. Furthermore, as noted in an earlier section (see Table 6), the younger participants' implicit learning performance was also associated with explicit knowledge of the artificial grammar. However, none of these findings were significant with the older participants. Thus a series of significant relationships between various explicit measures and AG task performance were revealed with the younger participants, while no such relationships were evident with the older participants. One interpretation of

this finding is that perhaps, because the younger participants reported significantly more explicit knowledge of the rules used in the AG task, explicit processes may have played a larger role in the performance of the young participants on the AG task. Therefore, significant associations were found in the young group, between performance on the AG task, explicit pattern completion task performance, and the amount of explicit knowledge acquired during the AG task. Conversely, because the old participants seemed to acquire little or no explicit knowledge of the artificial grammar, the AG task may have remained a purer implicit learning assessment for the aged sample. Thus, AG task performance was not associated to the reported knowledge of the artificial grammar or to explicit learning task performance.

The correlational findings suggest that while implicit tasks may not always tap into pure forms of implicit processes, on the whole they are in several important ways, qualitatively different from explicit processes.

Chapter 4

Discussion of Key Findings

Interpreting the Results from the Artificial Grammar Task

The primary finding produced by this study is the age deficit in the accuracy of responses for the Artificial Grammar (AG) task. The AG task has been employed repeatedly as a measure of implicit learning. Therefore, the age deficit found from the current study suggests that age may diminish implicit learning functioning, an observation which is contrary to the predictions put forward by Reber (1993). The age deficit is also contrary to much of the literature on aging and implicit learning (Prull, Gabrielli, & Bunge, 2000). Very few studies have investigated the AG task as it relates to aging, however the available studies suggest that age does not impact AG learning in any meaningful way (Meulemans et al., 1996; Salthouse et al. 1999). The evidence from other implicit learning paradigms further supports the notion that implicit processes are fairly resistant to age-related decay. Recently age independence in implicit learning performance has been demonstrated on a matrix scanning task involving implicit covariation learning (Schmitter-Edgecombe & Nissley, 2002) and a spatial contextual learning task (Howard et al., 2004). Furthermore, as noted earlier, several investigations of the effects of age on SRT task performance suggest that basic versions of the task are resistant to age-related decay.

Although several studies suggest a lack of age-related variance, the current study is not alone in reporting age-related deficits with implicit learning paradigms. It is noteworthy that the paradigms where no age effects have been reported are limited to one or two studies, while the SRT paradigm, which has received far more attention than the

other procedures, has produced age effects in several cognitively demanding variations of the paradigm (Frensch & Miner, 1994; Howard & Howard, 1997; Howard et al., 2004).

Differences in the AG and SRT tasks make it difficult to compare performance across tasks. However, it is interesting that age effects have been demonstrated with these paradigms while age effects have yet to be uncovered with other implicit learning procedures. Howard et al. (2004) propose that age deficits were found with an Alternating Serial Response Task (ASRT) with high (third or fourth) order dependencies embedded in the sequences, but were not evident in a fairly sophisticated spatial contextual learning paradigm because the two tasks tap into different cognitive mechanisms. They propose that ASRT sequence learning recruits fronto-striatal-cerebellar circuitry and that these areas are associated with non-demented typical age-related declines. The spatial contextual task, however, appears to rely on medial temporal lobe (hippocampal) brain structures which Howard et al. (2004) argue are usually not adversely effected by typical, non-demented aging patterns. The authors posit that these findings indicate a disassociation in implicit learning mechanisms:

> "In summary, we believe that the dissociation between contextual cuing and sequence learning reflects the differential aging of the brain systems underlying the two context learning tasks. Sequence learning depends on the relatively impaired fronto–striatal–cerebellar system, whereas contextual cuing relies instead on relatively preserved medial temporal lobe structures." (p. 132)

It is worth considering how the results and interpretations offered by Howard et al. (2004) can illuminate the age deficits in AG performance from the current study. The Howard et al. procedure assesses implicit learning by comparing response times (RT's) and error rates for patterned and random trials embedded in the sequences across a series

of blocks. Both age groups demonstrated learning of the sequence as their RT's and error rates improved across the learning blocks for the patterned trials more than for the random events. In all conditions of the study, the old subjects were significantly slower than the young participants, yet were more accurate with their responses. However, despite their increased accuracy the older participants showed lower levels of learning as their responses for patterned trials did not diverge as dramatically from the random events across the blocks. In contrast, the AG study presented in this thesis, indicated that older participants were both slower and less accurate with their responses. Furthermore, there were several reasons to assume that slower RT's were related to the reduced accuracy in making grammatical assessments, as slower RT's were associated with reduced accuracy both within subjects (see the SR analyses and figure 11) and between the age groups, as evidenced by the age differences in RT and accuracy (PC). In addition, processing speed was negatively correlated with accuracy and RT among the older participants. These associations do not establish that age-related cognitive slowing is responsible for the age deficit in AG performance, but they allow for the possibility of a causal relationship of this sort. Similarly the age-related processing speed declines may have contributed to the age deficits on the ASRT. It has been proposed (Howard & Howard, 1997, 2001, 2004; Negash, Howard, Japikse, & Howard, 2003) that the age deficits in the SRT paradigm may have arisen from reduced working memory capacity via the simultaneity mechanism proposed by Salthouse (1996). Therefore, the age deficits from both the SRT and AG paradigms may be partially mediated by age-related processing speed and/or WM capacity declines and not from declines in implicit learning.

Despite the claims made by Howard et al. (2004), the available data fail to establish that the differing age effects are dissociable from one another as the different results across tasks may have arisen from differences in WM capacity demands and/or from age-related processing speed declines and not due to distinctive neural processing demands across tasks.

Returning to the current AG study, the relations between processing speed and AG task performance falls far short of explaining all of the age-related variance. However, alternative explanations for the observed age deficit were implicated by the analyses. Another especially relevant set of findings relate to the reported levels of explicit knowledge of the artificial grammar. The younger participants reported significantly higher levels of explicit knowledge of the AG than the older participants. Furthermore, the percentage of correct AG responses for the young participants was significantly associated with their reported explicit knowledge of the grammar, while no such relationship was found among the older participants. These findings clearly suggest that part of the age deficit may be rooted in explicit process contamination of the task.

Once again the relationship between explicit knowledge of the grammar and AG learning explains only a small portion of the age deficit. However, the measure of explicit knowledge of the grammar was by no means exhaustive. It has yet to be determined if a more systematic measure of explicit knowledge acquisition would effectively reduce the age deficit, yet the data from the current study certainly make such an assertion reasonable. The vast literature on aging and implicit memory provides an even more compelling reason to hypothesize that observed age deficits in AG learning could be explained by explicit contamination.

Implicit memory studies have effectively demonstrated that even when previously presented stimuli are not explicitly recalled, the stimuli often serve as primes for future responding. Aging studies employing implicit memory tasks have produced a very mixed set of findings, and as a result, a mixed set of interpretations. Six studies with large samples (n >150) have been conducted investigating the effects of age on implicit memory. Significant age effects were found in three of the studies (Davis et al., 1990; Hultsch, Masson, & Small, 1991; Small, Hultsch, & Masson, 1995), while three of the studies found no significant age effects (Maki, Zonderman, & Weingartner, 1999; Nyberg, Bläckman, Erngrund, Olofsson, & Nilsson, 1996; Park & Shaw, 1992). Furthermore, several meta-analyses have also been performed and have produced very different findings. Fleischman & Gabrielli (1998) and Light and her colleagues (La Voie & Light, 1994; Light & La Voie, 1993; Light, Prull, La Voie, & Healy, 2000) both concluded that age produces small but significant age-related declines in implicit memory performance. In fact Light et al. (2000) proposed that "we can reject the hypothesis that there are no age differences in repetition priming" (p. 253). However, Mitchell and Bruss (2003) shrewdly point out that none of the aforementioned meta-analyses accounted for explicit memory contamination in the implicit memory paradigms. Mitchell (1995) conducted a meta-analysis of 36 studies and revealed that any initial age effects virtually disappeared when explicit memory contamination was accounted for. Specifically, older participants tended to report less explicit memory for items and the age differences found in various implicit memory procedures were largely rooted in differences in explicit memory contamination and not from differing priming effects. Mitchell & Bruss conducted a series of experiments investigating the effects of age on five implicit

memory paradigms with a special focus on explicit memory contamination in each of the paradigms. Their experiments revealed no age effects in any of the tasks. The authors concluded:

> "The study provides strong support for the stability of implicit memory. Older adults displayed priming similar to the young adults across five implicit memory measures despite deficits on explicit memory and neuropsychological tests. This stability did not vary as a function of task classifications, including perceptual-conceptual or identification-production distinctions." (p. 820)

These findings offer a clear demonstration of how explicit processes can often infiltrate task paradigms labeled as implicit and muddle both the results and the discussions of the results. Although in the current AG study, the data merely suggest that explicit contamination contributed to the age deficit, and do not account for the bulk of the deficit, it is possible that if explicit knowledge of the grammar is somehow quantified in a systematic fashion the age deficit may be attenuated even further.

Mitchell and Bruss (2003) emphasize the lack of age effects across all implicit memory paradigms and use their findings to argue that implicit memory mechanisms are resistant to age-related decay. In contrast, Howard and Howard (2004) postulate that because age deficits were found with a higher order sequence learning task (ASRT) and were absent with a contextual cuing paradigm, it is likely that these tasks are distinct implicit learning tasks tapping into different neural substrates. Mitchell and Bruss were careful to control for explicit contamination of the task and attribute the lack of age effects to this control. However, it is unlikely that explicit contamination contributed to the age deficit on the ASRT employed by Howard and Howard, as there were no age differences in reported levels of explicit knowledge for the sequence. As noted above,

however, Working Memory (WM) and/or processing speed have yet to be convincingly excluded as the root causes of the age deficits in the ASRT procedure. In fact because the older participants show reduced learning with high order dependencies and no deficits with low order contingencies, WM appears to be pivotal in the observed age deficits. Therefore, the different findings in the implicit learning and implicit memory literature appear to be rooted in the different demands of the various paradigms. Designing an implicit memory task with similar high order contingencies to assess whether such a task would also produce an age deficit would effectively test this hypothesis.

Another issue raised by the results from the current AG study pertains to the impact of the response limit manipulation on the accuracy of the well-formedness decisions. As previously described, the young participants were more accurate in all conditions, however, the age groups were influenced by the response limit conditions differently. Specifically, the old participants were significantly more accurate with their short response limit decisions while the young participants tended to be more accurate (although not significantly more accurate) with their long response limit decisions (see figure 9). The implications of these findings are that the older participants benefited from being encouraged not to deliberate while the young participants seemed to benefit from the extra time in the long response limit condition. Longer response times are generally associated with top-down, explicit decision making processes. The younger participants, who reported significantly more explicit knowledge of the AG, were just as accurate when they were allotted more time to respond perhaps because the extra time allowed for their explicit knowledge base to be utilized. The older participants who showed limited explicit knowledge of the grammar, were less accurate when given extra time in the long

response limit, perhaps because of their lack of an accurate explicit knowledge base. Based on this interpretation an obvious problem arises from the fact that the speed of responses were inversely related to accuracy with slow responses being far less accurate and fast responses more accurate across both age groups. However, as noted above, the inverse relationship between the speed of responses (SR) and accuracy of responses (PC) is probably the result of within-subjects' factors and offer limited insights into the age group differences. Specifically, for both age groups, the SR effect likely arose because individual participants took more time to respond to the items they found more challenging.

There is some precedent for the notion that longer response limits may produce explicit contamination on implicit tasks. Mitchell and Bruss (2003) took pains to reduce explicit contamination in various implicit memory tasks. One of their procedures was to "entice participants to focus on responding rapidly and limit the time available for those who might try to think back to the study list" (p. 819). They argued that these manipulations, among others, helped to improve the implicit memory methodologies and proposed that the smaller age differences found in their experiments were "due to improved procedures." In Mitchell & Bruss' own words:

> "the number of usable age effect sizes in the meta-analyses by Light and her colleagues over the years from 1993 to 2000 grew from 33 to 89, whereas the magnitude of these effect sizes shrank from .338 to .185.... Part of the reason for this decrease in effect sizes-even with the increase in power and the number of studies-is improved methodology." (p. 819)

The implicit learning literature has yet to perform as thorough an analysis of explicit contamination in implicit learning task performance as it relates to aging. Such an

enterprise would be desirable, particularly for the AG task which seems especially prone to explicit contamination, although measurement of explicit acquisition can be quite elusive. It is generally accepted that at least some of the knowledge acquired during AG learning is explicit. There have been several demonstrations of acquired explicit knowledge during an AG procedure including awareness of letter pair associations (Perruchet & Pacteau, 1990), chunk strength information (Meulemans, & Van der Linden, 1997; Pothos & Bailey, 2000), similarity, (Pothos & Bailey, 2000) and repeating patterns (Gomez, Gerken, & Schvaneveldt, 2000). It has been argued that AG learning is actually explicit learning of some basic rules and that while subjects are often unable to report their knowledge, with some probing, explicit knowledge is revealed (Dulany et al., 1984; Shanks & St. John, 1994). According to this view participants often gain explicit awareness of bigram and trigram letter combination and other physical feature of the stimulus array and that explicit knowledge of these features explains much of the AG learning. There is little doubt that explicit processes contribute to overall AG learning. However, the view that AG learning can be explained entirely through explicit learning mechanisms is not supported by the literature (see Mathews et al., 1989; Reber, 1993). It is more likely that both implicit and explicit acquisition contributes to AG learning and while the extent to which each mode of acquisition contributes to overall learning is a hot button issue among cognitive psychologists, it is highly unlikely that even the majority of AG learning can be explained away as explicit. The current study, for example, showed that while the older participants actually reported very few accurate rules for the grammar, they still performed well above chance on the artificial grammar task, suggesting that their performance was largely dependent on implicit and not explicit

learning processes. Nevertheless, it would be interesting and worthwhile to compare different age groups on the various paradigms designed to assess explicit knowledge acquisition during an AG task. If age deficits are discovered in the level of explicit knowledge of bigrams, trigrams, and other physical features, they may better explain the observed age deficit in AG learning in the current study. While there are still many issues of design and protocol to iron out, it is clear, that when the issue of explicit contamination of the AG task is better understood, the effects of age on AG learning can then be investigated with more precision.

While the findings for the age deficit in AG learning and the effects of the response limit manipulation were both unexpected, both results have several intriguing theoretical implications. The instructional manipulation, however, while also surprising, offers very little wiggle room for speculation. Both age groups were significantly more accurate during the intentional condition of the AG task and the instructional effect was evident across both the long and short response limit conditions. The intentional condition was designed to recruit explicit processes while the incidental instructions were meant to draw on mostly implicit processes. Turner and Fischler (1993) employed a similar AG task with similar instructional (explicit vs. implicit) and response limit (2-sec. vs. 6 sec.) conditions, but their findings were somewhat different from those described in the current study. They reported that responses were significantly more accurate during the long response limit condition, and they found no overall differences between the instruction groups. Additionally, their data revealed that participants who received explicit instructions were significantly more accurate with the long response deadlines while there was no response limit effect for participants who received an implicit set of

instructions. The data from this thesis also showed that the younger participants were a bit more accurate with their short response limit responses, and while this difference failed to reach significance, it was in the same direction as the response limit effect reported by Turner and Fischler. Unfortunately, all of the other results presented by Turner and Fischler were different from the results of this study. An important difference between the protocols used by Turner and Fischler and the current study is that while the learning phase of the current study presented learning strings on the screen one at a time, Turner and Fischler presented several strings at a time with either a salient (three strings with similar structures were presented simultaneously on the screen) or non-salient (three strings with differing structure were simultaneously presented) stimulus set. The differences in procedure may partially explain the different results, but nonetheless, the contradictory findings are puzzling.

Another more recent study conducted by Helman and Berry (2003) also manipulated instructions (implicit and explicit) and response limits (2.5 sec and no deadline), however the instruction groups were created with a novel procedure. The instructional manipulation was implemented prior to the test phase of the AG task as participants receiving implicit instructions were told to make "liking" judgments based on their "gut feelings" while participants receiving explicit instructions were told to base their "liking" decisions on the level of similarity between the test items to the items presented during the learning phase. Helman and Berry reported that the explicit instructions produced higher levels of accuracy and that with implicit instructions participants were more accurate during the short response limit. Conversely, during the explicit condition, participants were more accurate with no deadline. Before comparing

the results reported by Helman and Berry to the results described in this thesis it should be noted that there were several differences in methodology. In the current study, participants were required to make Yes/No (Grammatical/Non-grammatical) judgments with the test items and were then asked for confidence ratings while Helman and Berry's experiment required likeness ratings on a 6 point scale for each of the test items. Furthermore, as noted earlier, there were differences in the details of the instructional and response limit manipulations. However, given the differences in methodology, the results from the two experiments are fairly similar. As noted above, the younger participants reported accurate explicit knowledge of the grammar, were more accurate with an intentional instructional set designed to tap into explicit decision making processes and tended to be more accurate (although this finding was not significant) during the long response limit condition. Similarly, Helman and Berry (2003) report an advantage with the explicit instructional set and that during the explicit instructional condition participants were more accurate with no response deadline. Helman and Berry also reported that during the implicit instructional condition higher accuracy levels were achieved with the 2.5 second response deadline and this finding is not paralleled in the current study. However, there is enough overlap in the findings to merit consideration that perhaps, for younger participants, explicit instructions produce higher levels of accuracy and, based on the findings from all three studies, it is likely that response limits may further impact the accuracy of responses. The results reported here indicate that response limits should not interact with the instructional conditions while the data of Helman and Berry (2003) and Turner and Fischler (1993) suggest that such an interaction should occur.

It is clear that the seemingly contradictory results are in need of resolution. Specifically, the response limit and instructional manipulations require further investigation to properly assess their effects on AG learning. The current study is among the first attempts to examine the effects of age on AG learning, but it also investigates whether varying the instructions and response limits differentially affect the old and young participants. Regarding the instructional effect from the current study, it is possible that participants in the intentional condition, who were informed of the existence of the grammar at the very beginning of the task, were more accurate because the awareness of the structure made participants in both age groups more vigilant during the learning phase offering an advantage during testing. It was predicted that the aged participants would be at a disadvantage with intentional instructions, as they were designed to tap into explicit learning mechanisms. Interestingly, the intentional instructions failed to produce greater levels of explicit knowledge, but produced higher levels of AG learning, suggesting that the manipulation was effective, but not in the way that was originally hypothesized. Instead, it seems that the intentional conditions resulted in improved implicit learning among both age groups and did not effectively impact explicit acquisition.

The data from this study strongly suggest that while an age deficit in AG learning was evident, it may be rooted in explicit knowledge acquisition and/or processing speed declines associated with age, and not solely from declines in implicit functions. Furthermore, both groups in this study exhibited better performance with an intentional (explicit) instructional set, and while the aged group was significantly more accurate with short response limits, no significant response limit effect was found among the young participants. Based on the mixed set of results produced by Turner and Fischler (1993)

and Helman and Berry (2003), it is clear that the effects of response deadlines and instructional manipulations are in need of further study and the methods of assessing explicit knowledge acquisition during the AG task are in need of refinement so they can be utilized with an aged population. After these methodologies are improved a replication of this study would be in order to help fill in some of the theoretical gaps exposed by these results.

The Age Deficit in the Explicit Pattern Completion Task

Age deficits in the accuracy and speed of responses were also found with the explicit pattern completion task. Older participants were expected to require more time to solve each pattern successfully. It was therefore hypothesized that the short response limit condition of the explicit task would produce an especially large age deficit while the age deficit would be far less dramatic during the long response limit condition. The data, however, were not consistent with this hypothesis, rather they revealed similar age deficits in both conditions. This finding while unanticipated, is easily reconciled with the many demonstrations of age deficits in explicit tasks as the older participants were less accurate with their responses, slower with their responses, and late on significantly more items.

A strong indication that the pattern completion task successfully tapped into top-down explicit processes was that for both old and young participants, increased confidence was strongly associated with increased accuracy (see Figure 29). This association between confidence and accuracy suggests that participants had explicit awareness of the accuracy of their responses signifying that success on the task was dependant on successful explicit learning. In contrast, high confidence ratings on the AG

task were somewhat associated with higher accuracy levels for the young participants, but not for the older participants (see Figure 16). This finding supports the notion that explicit processes may have enhanced AG learning for the younger participants, but that the older participants were unable to utilize explicit acquisition to bolster their AG learning. The significant relationship between explicit pattern completion task performance and the reported explicit knowledge of the artificial grammar among the younger participants and the lack of such a relationship among the older participants offers further support for this view (see Table 12).

Working Memory and Processing Speed.

The results from the working memory and processing speed measures were fairly straightforward as no age deficits were apparent in the working memory measures, while profound age deficits were found with the processing speed measures. The lack of an age deficit in the working memory measures is a testament to the excellent cognitive health of the aged sample that volunteered to participate in the study. The older volunteers tended to be highly educated, motivated, and very inquisitive participants. Given that the average age of the participants in the aged group was 75.4, an age deficit in WM capacity was expected. However, since the older participants were volunteers and were members of a high functioning and active network of seniors taking classes at Brooklyn College, they were far from typical and their performance on the WM measure was demonstrative of this fact. Nonetheless, the age deficits were dramatic for the processing speed measures as these measures are far more sensitive to age-related declines.

The primary function of the working memory and processing speed measures was to determine the basis of any age related deficits found in the AG and explicit pattern

completion task. In general, the processing speed measures were more reliably associated with performance on both the implicit and explicit learning tasks suggesting that processing speed may have contributed to the age-related variance on both tasks. Moreover, the processing speed measures were significantly associated with explicit acquisition of the rules employed during the AG task for the young participants, but not for the old participants. This finding further supports the conclusion that age-related cognitive slowing contributed, to the inability of the older participants to acquire explicit knowledge for the structure of the artificial grammar and therefore, may have contributed to the age deficit in AG learning.

Theoretical Considerations

Two attempts have been made to unify theories of implicit learning with theories of aging. Both accounts attempt to deemphasize the uniqueness of implicit processing by explaining age related variance in implicit and explicit tasks with the same basic mechanisms. Hoyer and Lincourt (1998) argued that all age related differences found in both implicit and explicit learning tasks are probably caused by age related differences in processing speed and other mechanisms like chunking and associative learning. Similarly, Salthouse et al. (1999) posited that the age related variance in implicit and explicit tasks are rooted in their reliance on whatever cognitive mechanisms contribute to age related declines, be it cognitive slowing or reduced working memory capacity. While these arguments are reasonable, and are supported to some extent by research on aging and implicit learning, both theoretical views attempt to deemphasize any proposed dissociation between the implicit and explicit systems. These theoretical attempts acknowledge that implicit learning does not seem to decay with age to the same extent as

explicit learning, but the lack of age related variance in implicit task performance is thought to be rooted in the same aging mechanisms that impact other cognitive domains.

As mentioned above, arguing against the systems view of implicit and explicit learning, Hoyer and Lincourt (1998) are ignoring the empirical evidence in the areas of neuroscience (Baldwin & Kutas, 1997; Curan, 1998; Gabrieli, 1994; Lieberman et al., 2004; Seger, 1994; Seger et al., 2000; Squire et al., 1993; and) and development (Gomez & Gerkin, 1999; Meulemans et al., 1996; Saffran et al., 1996a, Saffran et al., 1996b; Haith, et al., 1993; Howard & Howard, 1989, 1992) which strongly suggest a dissociation between the implicit and explicit system. The same can be stated regarding Salthouse et al. (1999) who purport that the relatively small age related variance found with implicit learning procedures was rooted in the implicit learning task's lack of dependence on processing speed and/or working memory processes which are thought to contribute to age deficits on a host of cognitive tasks. Salthouse et al. (1999) emphasize the explanatory power of processing speed and working memory to explain age deficits or the lack thereof on cognitive tasks, however, they ignore the fact that the lack of an age deficit is predicted by the system's view of cognition where implicit and explicit processes are viewed as parts of two largely distinctive cognitive systems.

This seeming tension can be alleviated simply by allowing for the possibility that while the implicit and explicit systems are largely separate, they do share in some basic functions (Mathews et al., 1989). It is entirely possible, and based on some of the evidence from the SRT and AG paradigms, even likely, that while implicit learning is more resistant to age related decay, it does rely on processing speed and/or working memory to some extent. In this theoretical context, age related declines in processing

speed and/or working memory contribute to age related declines in implicit and explicit functions.

The idea that age deficits in implicit processing arise from the same cognitive factors that contribute to explicit cognitive declines is by no means antithetical to the notion that the implicit system is dissociable from the explicit system. There is a vast literature where various neurological and/or psychological conditions varying from schizophrenia (Abrams & Reber, 1988) and depression (Rathus et al., 1994) to amnesia (Knowlton, Squire, & Ramus, 1992), and Alzheimer's disease (P. J. Reber, Martinez, & Weintraub, 2002), exert dramatic effects on explicit task performance and have little or no impact on implicit task performance. However, there are to date, no studies demonstrating deficits in implicit and not explicit functions. It is unlikely that the lack of such findings can be attributed to the fact that implicit tasks are easier, as several of the implicit learning paradigms are based on fairly sophisticated rule systems. A more likely explanation is that the implicit system functions largely independently from the explicit system, however, under certain conditions, implicit tasks place demands on secondary internal cognitive mechanisms like processing speed and/or working memory. When implicit tasks tap into these secondary internal factors, deficits in special populations such as the aged population employed in the current study emerge. It is also possible that the age deficits found with implicit tasks may be, at least partially, rooted in explicit task contamination. That is, the explicit component embedded in implicit tasks contributes to age related variance via increased dependency on processing speed and/or working memory. To rule out this possibility the effects of explicit processing needs to be

properly quantified and controlled so that cleaner comparisons can be made between old and young participants and between neurologically compromised and healthy individuals.

Alternatively, newly developed neuroscanning techniques can be employed to further our understanding of the processing demands made by the AG task. Several studies utilizing fMRI techniques have shown evidence for differential processing of implicit and explicit tasks. P. J. Reber, Gitelman, Parrish, and Mesulam (2003) discovered that participants who approached a dot-pattern classification task from an implicit perspective showed primarily occipital cortical activity while those who were instructed to try to find the patterns in the displays showed medial temporal lobe activity. In a study employing the AG paradigm, Seger, Prabhakaran, and Poldrack (2000) showed evidence for a dissociation between explicit and implicit approaches to AG learning. In addition, a recent study by Lieberman, Chang, Chiao, Boohheimer, & Knowlton, (2004) provides some much needed insights as to the processing demands made by the AG task. Lieberman et al. report that with an AG task, well-formedness decisions that were made based on chunk strength were linked to medial temporal lobe activation while well-formedness decisions based on rule adherence were linked to activity in the right caudate nucleus. The authors conclude that:

> "activation in the caudate nucleus may play a role in applying the implicitly learned rules that contribute to performance, that activation in the hippocampus and medial temporal lobe may play a role in retrieval of chunks from training items, and that these processes may operate in a competitive, rather that a complementary, fashion." (p. 435)

The findings reported by Lieberman et al. (2004) suggest that the AG task recruits both implicit (caudate nucleus-rules) and explicit (medial temporal lobe-chunks) decision

making processes. The fact that there seems to be implicit and explicit decision making processes contributing to performance on the AG task significantly strengthens the notion that the AG task is not a purely implicit task and that it does in fact recruit explicit decision making processes. What remains unclear is whether the age differences in AG learning found in the current study are directly related to age differences in explicit acquisition for certain aspects of the grammar. A replication of the Lieberman et al. study with an aged population would likely shed some much needed light on this issue.

Future Research

The results from the current study illuminate the need for further research investigating the effects of differing instructional sets and response limit conditions on artificial grammar learning. When these effects are better understood, they can be applied to varying age groups to further elucidate the effects of age on artificial grammar learning. A more comprehensive understanding of the extent that explicit processes contaminate the artificial grammar learning paradigm is also essential in understanding the true impact of age on implicit acquisition during the artificial grammar procedure. The current study revealed a significant age deficit in AG learning, but it was difficult to determine the underlying factors that contributed to the age deficit. An additional experiment was conducted that relates in several ways to the current AG study. The new study assessed AG learning in a sample of Traumatic Brain Injury (TBI) patients from Peninsula Medical Center. While the data are still in the process of being collected and analyzed, there is a strong suggestion of a significant age deficit in AG learning among the TBI patients compared to a group of college-aged controls (see Appendix B). While the TBI study did not assess explicit contamination, the study utilized a comprehensive

battery of cognitive tasks to assess explicit functioning, processing speed, working memory, reasoning ability and several other cognitive factors. It will be interesting to see if the deficit in AG learning among the TBI patients can be effectively linked to any of these other cognitive functions.

The current study presents a test of Reber's (1992, 1993) evolutionary theory of the cognitive unconscious in that it demonstrates a large age deficit with an implicit learning paradigm. However, it also challenges theories of aging and implicit learning in that it suggests that while artificial grammar learning may be at least partially dependent on internal factors such as processing speed and working memory, it is also likely to be contaminated by explicit acquisition. Based on these findings it is possible that processing speed and working memory impact explicit learning of the artificial grammar and not necessarily implicit acquisition.

Further study is needed to resolve these issues. In the meantime, theories of aging and implicit learning should begin to acknowledge the wealth of evidence suggesting a dissociation between implicit and explicit systems. While it is likely that the two cognitive systems share in some processing, they should be considered as largely separate systems with the implicit system being a more diffuse system showing less age-related variance than the explicit system. This view can be tested with a simple replication of the following study with some slight adjustments in the methods to better assess for explicit contamination and for the effects of working memory and processing speed.

Appendix A

Instructions for The Implicit Learning Task

Incidental instructions for the AG task presented at the beginning of the task

WELCOME TO OUR EXPERIMENTS ON MEMORY

Okay, let's start. This is an experiment on human memory, but unlike most studies of memory, we will be using stimuli that have no real meaning. Specifically, we will be working with unpronounceable sequences of letters from 3 to 8 letters long.

For example, the stimuli will look like, DHDXHDM.

What we are going to ask you to do is simple: Just memorize each string of letters as it appears on the monitor as quickly and efficiently as possible.

That's all there is. Okay? Do you have any questions? It is important that you understand what we are asking you to do here, so if there is anything that is not clear, please ask me about it.

Okay, we're ready to begin. There will be three parts to this experiment. Press the 'Space Bar' to see the instructions for the first part.

Intentional instructions for the AG task presented at the beginning of the task

WELCOME TO OUR EXPERIMENTS ON MEMORY

Okay, let's start. This is an experiment on human memory, but unlike most studies of memory, we will be using stimuli that have no real meaning. Specifically, we will be working with unpronounceable sequences of letters from 3 to 8 letters long.

These letter sequences were generated by a complex set of rules that control letter order. You can think of these rules as being like the rules of a language. We can say something like "The boy hits the ball" but we cannot say "Hits ball boy the the." There are rules that determine the order of words in a language.

In our case we will not being looking at real words but at nonsensical sequences of letters, like DHDXHDM but, there are still rules that we have developed that determine which letters can occur in particular places in each sequence.

These rules that determine letter order are pretty complex and the task isn't easy. After we've gone through the learning phase of the experiment, we're going to ask you some questions about the rules.

So, it will be to your advantage if you can figure out what these rules are.

Okay? Do you have any questions? It is important that you understand what we are asking you to do here, so if there is anything that is not clear, please ask me about it.

Okay, we're ready to begin. There will be three parts to this experiment. Press the 'Space Bar' to see the instructions for the first part.

Copy phase instructions for all AG task conditions

MEMORIZING THROUGH COPYING

In this part of the experiment, those unpronounceable letter sequences I told you about will appear on the screen. They will vary from very short strings only 3 letters in length to others 8 letters long.

For now, your task is simply to copy down each letter sequence on the paper next to you. The string of letters will remain on the monitor until you are done.

After you've finished copying the sequence, press the 'Space Bar' and the computer will present you with the next string of letters.

After we've finished with this copying task, you will be asked to memorize these strings so the more attention you pay to the letter strings now, the easier it will be to memorize them later on.

There will be a total of 40 letter strings and this part of the experiment will be divided into 2 blocks, with 20 letter sequences to copy in each block.

Okay? Again, if you have any questions about what we're about to do, please ask them now. When you are ready to begin, press the 'Space Bar.'

Test phase instructions for the incidental instructions and short response limit condition of the AG task

TEST PHASE: EXAMINING WHAT YOU HAVE MEMORIZED

Congratulations!!! You have successfully memorized all of the letter strings.

We are now changing gears a bit and asking you to do something different. In case you hadn't noticed, those letter strings you worked with were all patterned. That is, while you may have thought they were just haphazard letter sequences, they were actually constructed using a complex set of rules that controlled which letters could be in particular locations.

In this part of the study we want to see if you have, perhaps without even realizing it, learned something about those rules.

Here's how we'll do it. We will now show you another set of letter strings, some of them obey the rules and some do not. That is, some of the letter strings are "well-formed" and some are not.

If you're confused about what we mean by well formed, think about English grammar. We can say "The boy hit the ball" but we cannot say "Boy ball hit the the." The first is "well-formed", the second is not.

Your task is simple, look at each letter string when it appears on the monitor and judge whether or not you think it conforms to the rules. If you believe it is "well-formed" and follows the rules, press 'Y' (for 'yes'); if you think it violates the rules in some fashion, press 'N' (for 'no').

We want you to treat this task in a very intuitive, rapid fashion. Actually, we don't really want to think very much about your answers. So, you're only going to have 3 seconds to make your decision. If you fail to respond in time, the computer will prompt you to respond immediately. If you are late in responding and the prompt appears, simply

wait for the prompt to disappear and make your response, but do not respond while the prompt is still on the screen.

Please try to keep all of your responses within the 3 second time limit.

We are also interested in how sure you feel about each judgment. So after pressing the 'Y' or 'N' key, the computer will ask you to tell us how confident you are in your judgment. Here you simply press either '1', '2', or '3'. If you are very certain about your answer press '3'; if you are only slightly sure, press '2'; if you feel you are just guessing, press '1'.

There will be 100 strings of letters to look at here. Just so you have some feeling for what is going on, you should know that exactly half or 50 of these strings are, in fact, correct and half contain an error somewhere.

This part of the experiment is divided into 2 blocks with 50 letter strings in each block.

Okay? Any questions? Press the 'Space Bar' when you are ready to begin.

Test phase instructions for the incidental instructions and long response limit condition of the AG task

TEST PHASE: EXAMINING WHAT YOU HAVE MEMORIZED

Congratulations!!! You have successfully memorized all of the letter strings.

We are now changing gears a bit and asking you to do something different.

In case you hadn't noticed, those letter strings you worked with were all patterned. That is, while you may have thought they were just haphazard letter sequences, they were actually constructed using a complex set of rules that controlled which letters could be in particular locations.

In this part of the study we want to see if you have, perhaps without even realizing it, learned something about those rules.

Here's how we'll do it. We will now show you another set of letter strings, some of them obey the rules and some do not. That is, some of the letter strings are "well-formed" and some are not.

If you're confused about what we mean by well formed, think about English grammar. We can say "The boy hit the ball" but we cannot say "Boy ball hit the the." The first is "well-formed", the second is not.

You will have about 6 seconds to make your decision. Feel free to use as much of the 6 seconds as you want, but make sure to respond before time is up. If you fail to respond in time, the computer will prompt you to respond immediately. If you are late in responding and the prompt appears, simply wait for the prompt to disappear and make your response, but do not respond while the prompt is still on the screen.

Please try to keep al of your responses within the 6 second time limit.

We are also interested in how sure you feel about each judgment. So after pressing the 'Y' or 'N' key, the computer will ask you to tell us how confident you are in your judgment. Here you simply press either '1', '2', or '3'. If you are very certain about your answer press '3'; if you are only slightly sure, press '2'; if you feel you are just guessing, press '1'.

There will be 100 strings of letters to look at here. Just so you have some feeling for what is going on, you should know that exactly half or 50 of these strings are, in fact, correct and half contain an error somewhere.

This part of the experiment is divided into 2 blocks with 50 letter strings in each block.

Okay? Any questions?

Press the 'Space Bar' when you are ready to begin.

Test phase instructions for the intentional instructions and short response limit condition of the AG task

TEST PHASE: EXAMINING WHAT YOU HAVE MEMORIZED

Congratulations!!! You have successfully memorized all of the letter strings.

We are now changing gears a bit and asking you to do something different.

As mentioned earlier, the letter strings you worked with were all patterned. In this part of the study we want to see if you were able to figure out some of the rules that were used to generate the letter strings

Here's how we'll do it. We will now show you another set of letter strings, some of them obey the rules and some do not. That is, some of the letter strings are "well-formed" and some are not.

If you're confused about what we mean by well formed, remember our earlier discussion of the English language. We can say "The boy hit the ball" but we cannot say "Boy ball hit the the." The first is "well-formed", the second is not.

Your task is simple, look at each letter string when it appears on the monitor and judge whether or not you think it conforms to the rules. If you believe it is "well-formed" and follows the rules, press 'Y' (for 'yes'); if you think it violates the rules in some fashion, press 'N' (for 'no').

We want you to treat this task in a very intuitive, rapid fashion. Actually, we don't really want to think very much about your answers. So, you're only going to have 3 seconds to make your decision. If you fail to respond in time, the computer will prompt you to respond immediately. If you are late in responding and the prompt appears, simply wait for the prompt to disappear and make your response, but do not respond while the prompt is still on the screen.

Try to keep all of your responses within the 3 second time limit.

We are also interested in how sure you feel about each judgment. So after pressing the 'Y' or 'N' key, the computer will ask you to tell us how confident you are in your judgment. Here you simply press either '1', '2', or '3'. If you are very certain about your answer press '3'; if you are only slightly sure, press '2'; if you feel you are just guessing, press '1'.

There will be 100 strings of letters to look at here. Just so you have some feeling for what is going on, you should know that exactly half or 50 of these strings are, in fact, correct and half contain an error somewhere.

This part of the experiment is divided into 2 blocks with 50 letter strings in each block.

Okay? Any questions?

Press the 'Space Bar' when you are ready to begin.

Test phase instructions for the intentional instructions and long response limit condition of the AG task

TEST PHASE: EXAMINING WHAT YOU HAVE MEMORIZED

Congratulations!!! You have successfully memorized all of the letter strings.

We are now changing gears a bit and asking you to do something different.

As mentioned earlier, the letter strings you worked with were all patterned. In this part of the study we want to see if you were able to figure out some of the rules that were used to generate the letter strings

Here's how we'll do it. We will now show you another set of letter strings, some of them obey the rules and some do not. That is, some of the letter strings are "well-formed" and some are not.

If you're confused about what we mean by well formed, remember our earlier discussion of the English language. We can say "The boy hit the ball" but we cannot say "Boy ball hit the the." The first is "well-formed", the second is not.

Your task is simple, look at each letter string when it appears on the monitor and judge whether or not you think it conforms to the rules. If you believe it is "well-formed" and follows the rules, press 'Y' (for 'yes'); if you think it violates the rules in some fashion, press 'N' (for 'no').

You will have about 6 seconds to make your decision. Feel free to use as much of the 6 seconds as you want, but make sure to respond before time is up. If you fail to respond in time, the computer will prompt you to respond immediately. If you are late in responding and the prompt appears, simply wait for the prompt to disappear and make your response, but do not respond while the prompt is still on the screen.

Try to keep all of your responses within the 6 second time limit.We are also interested in how sure you feel about each judgment. So after pressing the 'Y' or 'N' key, the computer will ask you to tell us how confident you are in your judgment. Here you simply press either '1', '2', or '3'. If you are very certain about your answer press '3'; if you are only slightly sure, press '2'; if you feel you are just guessing, press '1'.

There will be 100 strings of letters to look at here. Just so you have some feeling for what is going on, you should know that exactly half or 50 of these strings are, in fact, correct and half contain an error somewhere.

This part of the experiment is divided into 2 blocks with 50 letter strings in each block.

Okay? Any questions?

When you are ready to begin the experiment press the 'Space Bar.'

Appendix B

Summary of Preliminary Findings from the Traumatic Brain Injury (TBI) Study

The table below represents the number of correct decisions made by the TBI patients at Peninsula Hospital and a control group of Brooklyn College undergraduate on an Artificial Grammar (AG) learning task with a regular test phase (AG Learning) and a transfer (AG Transfer) phase where the structure of the grammar was left in place, but the letter set was changed.

		Artificial Grammar Learning	
		AG Learning	AG Transfer
TBI Group	Mean	35.0	28.1
	N	13	12
	Std. Deviat	5.5	4.2
Control Group	Mean	39.1	33.6
	N	24	23
	Std. Deviat	3.9	3.6

The table below represents the number of correct decisions made by the TBI patients at Peninsula Hospital and a control group of Brooklyn College undergraduates on a selection of IQ measures.

		IQ Raw Scores	
		Similarities	Matrix Reasoning
TBI Group	Mean	14	5.0
	N	7	7
	Std. Deviati	9.5	4.3
Control Group	Mean	25.6	19.5
	N	28	27
	Std. Deviati	3.8	4.7

While this analysis is only preliminary, it is clear from the tables that there were group differences on all of the tasks. However, the deficit on the AG tasks were not

nearly as dramatic as were the deficits on the IQ measures. In fact the TBI patients performed significantly above chance (chance = 25) on both the AG learning and AG transfer phases. Therefore, while the level of overall AG learning appears to differ, there was significant AG learning in both conditions.

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