Recall In Aging and Alzheimer's Disease as a Function of Modality, Phonological Similarity, and Category

by

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ABSTRACT

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Since an inability to acquire and retain new information is the most prominent feature of early Alzheimer's Disease (AD) and is also present in normal aging, this study investigated variables relevant to the formation of new memories. Two goals were to develop a screening tool useful in early diagnosis of memory impairment and to gain insight into processes underlying the construction and formation of new memories.

Serial and free recall procedures were employed to assess immediate and delayed recall, respectively. Auditory and visual presentations of phonologically similar and dissimilar words and letters were used to determine the effects of modality of presentation, phonological similarity, and category upon correct responding. Relative to visually presented items, previous studies have demonstrated superior recall for final list items following auditory presentation in normal populations. Phonological similarity among items in lists has been demonstrated to attenuate recall relative to lists composed of

phonologically dissimilar items. Previous work has indicated that intrusion errors produced in AD patients may be phonologically related to the correct information to be recalled.

During both immediate and delayed recall, the young displayed the best performance followed in order by the elderly, mildly impaired, and AD groups. Effects of modality and phonological similarity were maintained throughout normal aging and during early AD. The phonological similarity effect was accentuated with age. During immediate serial recall all groups demonstrated superior recall for lists of letters relative to words. During delayed recall this pattern was reversed and all groups displayed superior recall for words.

All groups were able to maintain their responses within the proper category. The fewest number of intrusion errors were produced in the young with increasing amounts produced in the elderly, mildly impaired and AD groups. During immediate recall phonological similarity between items in lists produced perseveration in all groups, whereas phonological dissimilarity among items produced extra-list intrusion errors. The pattern of results obtained in this study supports previous findings and suggests age related impairment of the articulatory loop system of working memory as well as an integration of function between prefrontal cortex and the hippocampal formation.

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Alzheimer's Disease and Memory

Alzheimer's Disease (AD), which generally afflicts the elderly population and is responsible for over 50% of the demented individuals in the U.S. (Terry & Katzman, 1983), is first manifested in the form of memory impairment (Reisberg, Ferris, de Leon, & Crook, 1982). Later effects include disorientation, loss of the ability to function independently, and eventually death (Reisberg, et al., 1982).

At present, there are no reliable antemortem indicators of the disease that have high specificity. Extensive testing of cognition, neurological function, general medical health, and an impression of the person's functional ability obtained through interviews of the patient and an informant that maintains regular contact with the patient, are relied upon to make a diagnosis of probable AD according to standards put forth by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA) (McKhann et al., 1984).

It is believed that AD is caused by an accumulation of neurofibrillary tangles and beta amyloid plaques in the brain. The formation of tangles and plaques is thought to lead to cell death and, consequently, to disruption of connections between cells. Tangle formation typically begins in the region of the parahippocampal gyrus which includes the entorhinal cortex (Braak & Braak, 1993; Hof et. al, 1992; Price, Davis, Morris & White, 1991). Since the entorhinal cortex is a major contributor of projections to the hippocampus (Amaral & Insausti, 1990), cell loss in the entorhinal cortex essentially has the result of disconnecting the hippocampal formation from the rest of the brain.

Animal and human studies have indicated that the function of the hippocampal formation and surrounding structures, such as the entorhinal cortex, is to aid in the rapid acquisition and formation of new memories (Cohen & Eichenbaum, 1993; Eichenbaum, Mathews, & Cohen, 1989; Squire, 1992a; Squire, 1992b; Squire, et al., 1992; Squire & Zola-Morgan, 1991). Additionally, damage to the areas directly associated with the hippocampal formation, such as the entorhinal cortex, can produce more profound memory deficits than damage to the hippocampal formation alone (Squire, 1992b). In the earliest stage of AD, in which the entorhinal cortex is the most severely affected area, the most salient behavioral feature is the inability to retain new information (Albert & Moss, 1992; Morris et al., 1991; Welsh, Butters, Hughes, Mohs, & Heyman, 1991; Reisberg, et al., 1982).

The accumulation of tangles and plaques gradually spreads throughout the brain causing further disruption of connections among various regions within the brain. This increased disconnection between different areas of the brain results in further loss of function which may be displayed as increased levels of forgetfulness, an increasing inability to function independently, an eventual loss of motor ability and speech, and finally death (Reisberg, et al., 1982). What is generally considered to be the most definitive diagnosis of AD is usually obtained during autopsy by determining the quantity of neurofibrillary tangles and beta amyloid plaques in the brain tissue (Hirano & Zimmerman, 1962; Hyman, Van Hoesen, Damasio, Barnes, 1984; Hyman, Van Hoesen, Kromer, & Damasio, 1986; Morris, et al., 1991; Price, et al., 1991; Terry & Katzman, 1983), although some findings suggest that neocortical synapse density alone may provide a more discriminating measure (Terry et al. 1991).

Aging and Memory

The "normal" aging process, which may be defined as routinely occurring changes with increasing age that are not considered to be part of a particular disease state, also produces both structural changes in the brain along with functional changes in memory. Moscovitch and Winocur (1992) point out that the same functional changes that occur routinely with memory loss due to hippocampal dysfunction, such as a greater deficit for recent as opposed to remote memories, are also characteristic of memory performance in studies of normal aging in animals and humans.

Volumetric changes of the temporal lobe and hippocampal formation have been documented in the normal elderly population using magnetic resonance imaging (MRI) analysis of normal human brains. Jernigan, et al. (1991) found evidence for age associated changes in the mesial temporal lobe. More recently using MRI analyses along with neuropsychological measures of memory, Golomb et al. (1994) and Golomb et al. (1993) demonstrated that volumetric reductions in the hippocampal formation were associated with normal human aging as well as with decrements in delayed memory performance.

In addition to in vivo studies, histopathological studies have revealed increasing numbers of neurofibrillary tangles and beta amyloid plaques present in the hippocampal formation of normal controls with increasing age (Ball, 1977; Giannakopoulos, Hof, Mottier, Michel, & Bouras, 1994; Price et al., 1991). It should be noted, however, that although normal aging has been associated with changes in the hippocampal formation, these changes are generally found to be of a lesser degree than the changes that occur in the hippocampal formation during early AD.

Furthermore, during normal aging, many studies have demonstrated changes in other regions of the brain in addition to the changes observed in the hippocampal formation. Jernigan et al. (1991) found significant volumetric decreases in grey matter in most cortical regions. Price, et al. (1991) observed neurofibrillary tangles and beta amyloid plaques in other regions of the brain in addition to the hippocampal formation; while Giannakopoulos et al. (1994) observed neurofibrillary tangles and beta amyloid plaques in the superior frontal cortex. Moscovitch and Winocur (1992) suggest that the changes reported in the frontal lobes during normal aging may be of particular interest since the prefrontal cortex is believed to be an area that is important for complex cognitive functioning such as working memory.

Shimamura, Janowsky, and Squire (1990) have demonstrated that patients with frontal lobe lesions experience a deficit in the organization of temporal information; while amnesic patients, having both medial temporal lobe and frontal lobe pathology, display both a memory impairment, manifested as poor recall for newly acquired information, as well as a deficit in the organization of temporal information. Although Moscovitch and Winocur (1992) postulate frontal lobe changes as possibly being responsible for age associated memory impairment, they believe that memory deficits that accompany normal aging may be due to a combination of both hippocampal formation and frontal lobe dysfunction since older adults display characteristics of hippocampal formation dysfunction, such as impairment in the acquisition of new information, in addition to characteristics of frontal lobe dysfunction, such as difficulty organizing information temporally.

As can be inferred from the above discussion, a structural and functional overlap exists between the changes that occur during normal aging and early AD. Both normal aging and AD produce changes in the hippocampal formation which leads to a certain pattern of neuropsychological test results, specifically, the inability to recall recent information. Furthermore, AD patients are concurrently undergoing the process of aging. Therefore, AD patients may also display deficits characteristic of individuals with frontal lobe dysfunction, such as difficulty in the temporal organization of information. Although an overlap exists, the changes occurring in AD appear to reflect a greater degree of loss both structurally and functionally relative to changes that occur during normal aging. Differentiation between normal aging and early AD, therefore, may be enhanced by determining the relative degree of impairment on memory tests between these two groups.

Since an inability to acquire and retain new information is the most prominent feature of early AD and is also present in normal aging this study investigated variables relevant to the formation of new memories. If these variables are differentially characteristic of the memory impairment that occurs during the normal aging process and during AD, then this study may aid in the development of a screening tool which could be used for early diagnosis of memory impairment as well as possibly provide insight into the processes underlying construction and formation of new memories in general.

The remainder of this introduction will (a) describe the specific aims of this study, (b) define some of the variables that will be examined in this study, and (c) discuss the background and significance of the variables under investigation. The next section outlines the specific aims of this study.

Specific Aims

This study employed a serial recall paradigm to assess immediate recall and a free recall paradigm to assess delayed recall. Both auditory and visual presentations of phonologically similar and dissimilar words and letters were used to determine the effects of modality of presentation and phonological similarity upon correct responding. In addition to assessing the frequency of correct responses, an attempt was made to determine if phonological similarity among items in lists to be recalled has an effect upon the number and type of intrusion errors produced.

Briefly stated, the general hypothesis tested proposes that differential performance can be obtained between young and elderly normal controls, mildly impaired subjects (of which a portion can be considered incipient AD patients), and early AD patients when the information to be recalled varies with respect to presentation modality (silent reading versus reading aloud); phonological similarity among items; and category of information (words versus letters). The underlying assumption is that both the normal aging process and AD detrimentally affect structures involved in the encoding, storage, and retrieval processes of memory. With respect to differential performance between the four groups, an important aim of this study was to determine if different types and frequencies of errors occur and, if they do occur, whether these errors are related to the degree of impairment.

Definitions

The concept of recall involves the retrieval of information from memory. Immediate recall involves the retrieval of information directly following presentation of the material. Delayed recall refers to the retrieval of information following a period of time usually requiring a minimum interval of two minutes. Free recall is a procedure that requires the participant to reproduce the information presented without regard to order. Strict serial recall is a method of retrieval which demands that the exact order of presentation be maintained during the production of information from memory.

The modality effect refers to the superior recall of items at the end of an auditorily presented sequence relative to recall for items from the end of a visually presented sequence (Crowder, 1986; Crowder & Morton, 1969; Greene & Crowder, 1986; Laughery & Fell, 1969; Manning, Koehler & Hampton, 1990; Murray, 1966; Penney, 1975; Penney, 1989; Penney & Butt, 1986; Taub, 1975; Watkins, Watkins, & Crowder, 1974). The process of recoding refers to an alteration of the input stimulus from one type of representation to another. Phonological similarity, will refer to phonemic similarity or rhyme.

In this study Intrusion errors are defined as the production of stimuli not asked for during recall. Extra-list intrusion errors refer to information that was not presented during testing, yet was produced by the subject during recall. Previous-list intrusion errors refer to information that was presented during an earlier sequence or trial which the subject offered incorrectly for recall in a current sequence or trial. Perseveration refers to information that is repeated within a given sequence or trial.

Background and Significance

Immediate Recall

A large deficit in the immediate recall of early AD patients in comparison to elderly and young normal controls has been previously demonstrated under various conditions

(Mackell, 1993; Manning, Greenhut-Wertz & Mackell, in press). Under all conditions the immediate serial recall of early AD patients would be expected to be attenuated relative to elderly and young normal controls.

Recall of lists of items are often analyzed by plotting serial position curves: the number or proportion of correct responses at each serial position for all subjects. Primacy and recency are two effects routinely observed during the serial recall of lists. The primacy effect refers to the superior recall of items from the beginning of a list relative to items from the middle of the list. The recency effect refers to the superior recall of items from the end of a list relative to items from the middle of the list. One early interpretation of the primacy and recency effects proposed by Glanzer and Cunitz (1966) attributes the primacy effect to the ability to store items from the beginning of a list in long term or secondary memory while the recency effect is due to the ability to store items from the end of a list in short term or primary memory. Elderly normals display both primacy and recency effects (Manning & Greenhut-Wertz, 1990). AD patients have also demonstrated primacy and recency effects during immediate serial recall (Manning et al., in press).

Modality Effect

In normal populations, the modality of presentation, either auditory or visual, has been demonstrated to affect the recall of items from a list. In general, there is superior recall for the last item(s) following auditory presentation relative to visual presentation (Crowder, 1986; Crowder & Morton, 1969; Greene & Crowder, 1986; Laughery & Fell, 1969; Manning et al., 1990; Murray, 1966; Penney, 1975; Penney, 1989; Penney & Butt, 1986; Taub, 1975). This modality effect is maintained and accentuated in elderly normals (Arenberg, 1968; Manning & Greenhut-Wertz, 1990).

Arenberg (1968) found that the elderly performed better during auditory presentation of items in a list relative to visual presentation of items. The attenuated visual performance in the elderly produces a larger difference between the modalities than the difference observed between modalities in the young. The modality effect is similarly maintained and the difference accentuated in early AD patients (Manning et al., in press). Similar to the elderly, the attenuated visual performance of AD patients also produces a larger difference between modalities than the difference observed between modalities in the young.

Precategorical acoustic storage.

Numerous hypotheses have been proposed as explanations for the observed modality effect in normal subjects. Historically, the Precategorical Acoustic Storage (PAS) model (Crowder & Morton, 1969; Crowder, 1978; Morton, 1970; Watkins et al., 1974) had been proposed as an early explanation of the modality effect. The PAS model suggests that the modality effect occurs during recall by normal populations due to the operation of a memory system that is distinct from short term or primary memory. This additional memory system or PAS maintains an auditory memory trace that is not yet categorized and lasts longer than the analogous visual memory trace (Sperling, 1960) that would be available during visual presentation of a list (Watkins et al., 1974).

The PAS model has been discredited as an explanation of the modality effect. Evidence against this model includes the finding that a modality effect was still generated even though a distractor task was interjected both before and after every list item during both visual and auditory presentations (Gardiner & Gregg, 1979; Glenberg, 1984). If PAS is a sensory memory trace model, as suggested by Crowder and Morton (1969), then the distraction task should have overwritten, displaced or in some other way removed the temporary trace that would have allowed for superior recall in the auditory condition.

Similarly, if the PAS model is an auditory sensory memory trace model analogous to the visual sensory memory trace demonstrated by Sperling (1960), then information should be maintained in the store only for a relatively brief period of time. Therefore, the finding of a modality effect after an extended interval (60 seconds) elapsed between presentation of the list and recall provides further evidence against PAS (Engle & Roberts, 1982).

Watkins (1972) and Watkins and Watkins (1973) demonstrated that the modality effect was maintained even though the number of syllables in the words to be recalled varied. This finding indicated that the auditory properties, as implied by the PAS model, were not important for the superior recall in the auditory condition but rather the entire word was the unit of storage which would not be likely in a sensory store devoid of meaning. Based on the preceding as well as on other evidence, the PAS model has been rejected as a valid explanation of the modality effect.

Interference hypothesis.

If the PAS model of memory is not responsible for the observed modality effect then what else may be a feasible model to explain the modality effect? Interference has been proposed as another explanation for the modality effect. The hypothesis, proposed by Nairne (1988; 1990), states that the superiority of recall for items presented in the auditory modality relative to the visual modality may be due to a greater susceptibility to interference on the part of the visual modality memory trace. This interpretation, referred to by Nairne (1990) as a feature model of immediate or primary memory, reflects the differential performances observed between auditory and visual presentations. Based on Nairne (1990) the visual presentation would be predicted to display greater attenuation because the visual modality memory trace would be more likely to be affected by interference.

Nairne (1988) describes his view of immediate memory as a reconstructive process in which multiple memory traces are combined to form a complete memory. These memory traces, which are laid down during encoding and storage, are conceived as a collection of features or attributes. Successful retrieval depends on how well the features of each trace identify it as a member of the recall set. According to Nairne (1988) memory trace features are degraded by an overwriting process that occurs when new information enters memory. Therefore, end of list memory traces possess more identifying features which increase the likelihood of retrieval. Additionally, increased similarity among the information to be recalled can also increase the amount of overwriting that occurs and, hence, can increase the degradation of the features of a memory trace. Subsequent to overwriting, only those remaining trace features that uniquely identify members of the recall set will aid in the retrieval process.

Furthermore, according to Nairne (1988), there are two types of features or attributes. Modality independent features, referred to by Nairne as the "inner voice," represent a speech-like code which is dissimilar from the physical characteristics of speech. Modality dependent features represent the actual physical features of the input stimuli. Modality independent features are consistent with the primary linguistic code of Shand and Klima (1981).

Recency occurs following auditory presentation because the final list item contains more modality dependent (auditory physical) and modality independent (inner voice) features than previous list items because it is not overwritten by subsequent information. Following visual presentation, modality dependent (visual physical) features are rapidly lost. Decreased recency occurs following the visual presentation of items since subjects must rely solely on modality independent features (the inner voice) which are susceptible to the interfering effects of background cognitive activity that occurs during and immediately after list presentation.

Increased susceptibility to interference following visual presentations increases the attenuation of the recency portion of the serial position curve. This increased attenuation of the recency portion of the serial position curve yields a greater modality effect. This is precisely the direction of the effect observed in groups displaying greater susceptibility to interference (which may also be thought of as an increased inability to inhibit information).

Relative to young normal controls, elderly normals show a slight depression of the recency effect after visual presentation, and hence a greater modality effect (Manning & Greenhut-Wertz, 1990). Similarly, AD patients display a large depression of the recency effect after visual presentation relative to young and elderly controls, producing an increased modality effect (Manning et al., in press).

Recoding hypothesis.

The recoding hypothesis (Conrad, 1964; Baddeley, 1966; Laughery & Fell, 1969; Manning, et al., 1990; Wickelgren, 1965) states that visual stimuli are frequently recoded into an auditory representation, whereas, with auditory stimuli either no such recoding occurs or relatively less recoding is necessary. Recoding may account for the overall superiority of items presented in the auditory modality relative to visually presented items during strict serial recall because the recoding process may represent extra time during which material may be lost or confused (Manning et al., in press).

In comparison to young normal controls, it has been demonstrated that there is superior overall performance for auditory as compared to visual stimuli in elderly normal controls (Manning et al., in press; Manning & Greenhut-Wertz, 1990). Manning and Greenhut-Wertz (1990) postulate that this is due to deficits in the recoding of visual stimuli that occur with age. See Manning and Greenhut-Wertz (1990) for a more complete explanation of this hypothesis.

Another framework that proposes recoding processes during visual presentation is the working memory model

(Baddeley & Hitch, 1974; 1994). The concept of working memory as proposed by Baddeley and Hitch (1974; 1994) refers to a multicomponent system that is capable of manipulation and utilization of information in temporary storage. The information held in this temporary store may or may not be transferred into a long term storage.

The working memory system is divided into three basic components: a central executive and two slave systems that subserve the central executive. One function of the Central Executive System (CES) is to control attention demanding processes, such as the coordination of two or more tasks that require the use of memory simultaneously. The Articulatory Loop System (ALS) is one of the two slave systems to the CES in the working memory model.

The function of the ALS is to manipulate and store auditorily presented verbal material directly into the phonological store (a subsystem of the ALS dedicated to the storage of auditory verbal information). Visually presented speech based information is indirectly registered into the phonological store via articulatory subvocalization, which is a recoding process (Baddeley & Hitch, 1994). The Baddeley and Hitch (1974, 1994) concept of articulatory subvocalization, which occurs following the visual presentation of verbal stimuli, appears to be equivalent to the concept of recoding postulated by Conrad (1964), Manning et al. (1990), and Shand and Klima (1981).

Diverging hypotheses.

Although the Baddeley and Hitch (1974; 1994) model resembles the Manning et al. (1990) model with respect to recoding, the two hypotheses diverge regarding the proposed locus of dysfunction during normal aging and in early AD. Manning et al. (in press) postulate one possible locus of dysfunction regarding the accentuated difference between auditory and visual recall during normal aging and AD to be in the recoding process.

Morris and Baddeley (1988) propose an intact ALS and recoding process in AD based on the findings of Morris (1984) who demonstrated no significant difference between elderly control and AD groups with respect to the phonological similarity effect (suggesting an unimpaired phonological store in AD patients). Further evidence supporting the preservation of the phonological store in AD is the demonstration that phonemic cuing aids in the retrieval of information by AD patients (Neils, Brennan, Cole, Boller, & Gerdeman, 1988). Only an intact phonological store would allow AD patients to make use of phonological cues during auditory presentation.

Instead of a dysfunctional ALS Morris and Baddeley (1988) have suggested that AD patients possess a dysfunctional CES of working memory based on the findings of Baddeley, Logie, Bressi, Della Sala, and Spinnler (1986) that demonstrate an impaired performance in AD patients on memory tasks that require concurrent processing. Regarding normal aging and the CES, conflicting results exist. While Baddeley et al. (1986) report no difference between young and elderly normals with respect to the function of the CES; Salthouse, Rogan and Prill (1984) report that the CES was impaired in the elderly relative to young controls. Craik, Morris, and Gick (1990) suggest that this apparent discrepancy may be resolved by examining the tasks involved in both studies.

One interpretation offered by Craik et al. (1990), suggests that the Baddeley et al. (1986) study employed tasks that require a "microdivision" of attention; while the Salthouse et al. (1984) study employed tasks that require a "macrodivision" of attention, which involves different types of information or presents information in different modalities. Craik et al. (1990) implies that the latter type of task would reflect the function of the CES more accurately.

At this time, no studies exist comparing variables involved in the function of the ALS between young and elderly normal controls. If there is no significant difference between groups with respect to differences between modalities, then the view proposing an intact ALS during normal aging and during AD (Morris & Baddeley, 1988) would be supported. Conversely, if the difference between correct responding following visual presentation and correct responding following auditory presentation is greater in elderly controls than young controls and greater in AD patients than young controls then the view proposing an impaired recoding process (Manning et al., in press) would be supported.

An important feature of this study which has not been addressed in previous studies was the manipulation of both modality and phonological similarity for both aging and AD. In this way the function of the phonological store as well as measurement of the modality effect was simultaneously assessed throughout normal aging and during AD.

Modality effect: general considerations.

In general, with visually presented lists, it would be expected that all groups would show a decrease in performance relative to their performance following auditory presentation due to a modality effect. Regarding phonological similarity, Crowder (1978) demonstrated a modality effect for phonologically similar yet distinct words in the young population. However, Watkins et al. (1974) have demonstrated that, relative to lists composed of phonologically dissimilar items, the modality effect is slightly reduced when lists are composed of phonologically similar items.

Therefore, the modality effect would be accentuated across groups for lists composed of phonologically dissimilar items relative to lists composed of phonologically similar items based on the work of Watkins et al. (1974) and Manning and Robinson (1989). Additionally, based on the results of Manning and Greenhut-Wertz (1990) and Manning et al. (in press), normal elderly controls and early AD patients should display accentuated modality effects relative to young normal controls.

Phonological Similarity Effect

When items in a list to be recalled are phonologically similar to each other, recall for the items is suppressed relative to recall for lists composed of phonologically dissimilar items. This robust effect, known as the phonological similarity effect, has been demonstrated throughout normal aging (Baddeley, Lewis, & Vallar, 1984; Conrad, 1964; Conrad & Hull, 1964; Levy, 1971; Watkins, et al., 1974; Wickelgren, 1965) and during AD (Morris, 1984).

One explanation of the phonological similarity effect, couched in the terms of a working memory model, states that list items possessing similarity on a phonological basis also possess similar codes within the phonological store which can be more easily confused than the codes between phonologically dissimilar items (Baddeley et al., 1984). In general, recall would be expected to be attenuated across all groups for lists composed of phonologically similar items relative to lists composed of phonologically dissimilar items.

Category Effect

Providing lists of letters and words to be recalled allows an examination of how changing from one category of information to another effects the recall of items from a list in aging and AD. Substantial evidence exists that throughout normal aging and during AD, knowledge about category membership is preserved (Bayles, Tomoeda, & Trosset, 1990; Bayles, et al., 1989; Cronin-Golomb, Keane, Kokodis, Corkin, & Growdon, 1992; Hart, Smith, & Swash, 1988; Nebes, Boller, & Holland, 1986; Nebes & Brady, 1988; 1990; Martin & Fedio, 1983).

Additionally, Manning et al. (in press) demonstrated the ability to maintain information regarding category in elderly normal controls and early AD patients by the lack of extra-categorical intrusion errors during the recall of items from lists. Based on the results of Manning et al. (in press), elderly normal controls and AD patients should be capable of maintaining their responses within a circumscribed category of information even after the category of information presented for memorization is changed.

Effects of a Brief Delay

One of the most salient deficits in AD, measures of delayed recall (delayed recall defined as retrieval of information after a minimum period of 2 minutes between presentation and recall), have been demonstrated to be important in discriminating AD patients in the early stages of the disease from normal elderly control patients (Albert & Moss, 1992; Butters, et al., 1988; Moss, Albert, Butters, & Payne, 1986; Welsh et al., 1991). Additionally, delayed recall measures have been demonstrated as being significant in discriminating AD patients from other demented patients (Milberg & Albert, 1989; Moss & Albert, 1988).

Hart, Kwentus, Harkin, and Taylor (1988) have demonstrated that AD patients display a rapid rate of forgetting within the first ten minutes after presentation of information, but their rate of forgetting beyond the initial ten minute delay is no different than for controls. This finding demonstrates that it is the initial rate of forgetting that differentiates AD patients from normal elderly controls and other dementia patients. Therefore, the processing that occurs during this initial period may account for the memory deficit in AD patients.

Mackell (1993), and Manning et al. (in press) have recently studied the effects of brief delays upon performance in AD patients as well as young and elderly normal control subjects in order to determine effects of age and disease upon delayed recall. Manning et al. (in press) revealed poorer performance, identified by fewer correct responses and increased amounts of extra-list intrusion errors, in delayed recall for AD patients relative to young and normal elderly controls.

Since delayed recall has been demonstrated as being important in discriminating early AD patients from elderly normal controls, this variable is routinely used when screening an elderly population. The effects of a brief delay upon recall would be a progressive attenuation of correct responding in young normal controls, elderly normal controls, and AD patients where the AD patients would present the most attenuated performance and the young normal controls the least attenuated performance.

Intrusion Errors

Intrusion errors are also displayed as a form of memory impairment in AD patients. Intrusion errors have been demonstrated as being significant in differentiating AD from other dementias (Butters et al., 1987; Delis et al., 1991; Fuld, Katzman, Davies, & Terry, 1982; Helkala et al., 1989; Jacobs, Salmon, Troster, & Butters, 1990; Loewenstein et al., 1989; Massman et al., 1992). Extra-list intrusion errors have been demonstrated to be prevalent in AD patients relative to young and elderly normal controls (Bondi et al., 1994; Helkala et al., 1989; Loewenstein et al., 1989; Mackell, 1993; Manning et al., in press).

Additionally, intrusion errors have been shown to correlate with other measures of AD such as the number of senile plaques present at autopsy as well as with choline acetyltransferase (ChAT) levels (Fuld et al., 1982). ChAT is an enzyme responsible for the production of the neurotransmitter acetylcholine which is present in the hippocampus and has been demonstrated to be deficient in AD patients (Terry & Katzman, 1983). Finally, intrusion errors have been demonstrated to be useful in distinguishing AD patients from normal elderly controls (Helkala et al., 1989; Loewenstein et al., 1989; Massman et al., 1992) and diagnostically significant in the early detection of AD (Bondi et al., 1994).

Explanations for Production of Intrusion Errors

Lack of inhibition.

The inability to inhibit information may be responsible for the production of intrusion errors. An inhibition model, proposed by Hasher and Zacks (1988) to account for retrieval deficits in the elderly, suggests that inhibitory attentional mechanisms play an important role in cognitive processing by exerting control over the information that enters working memory.

The model, as originally stated, suggested that irrelevant information from the environment must be ignored or inhibited in order to attain a specific goal and that older adults experience difficulty when attempting to ignore such irrelevant information which would result in poorer scores on tests of recall (Gerard, Zacks, Hasher, & Radvansky, 1991; Hasher & Zacks, 1988). Subsequently, Stoltzfus, Hasher, Zacks, Ulivi, and Goldstein (1993) have suggested modifying the model so that it also pertains to the suppression of internal stimuli such as internal representations of previously rejected information rather than solely to the suppression of external stimuli.

Interference.

Closely related to a lack of inhibition is the concept of interference. Interference is a direct result of a lack of inhibition. The process of interference is by no means new to the study of memory. James (1890) proposed interference as a phenomenon that degrades primary memory.

More recently a model of increased internal interference due to decreased inhibition with advancing age has been proposed by Hebb (1978). Hebb (1976) suggests that with increased age, neurons that are not necessary for cognitive activity during a specific task tend to be disruptive and yield associated yet irrelevant ideas unless input from these neurons is inhibited. Some authors, Olton and Shapiro (1992) and Nadel (1992), believe that the major role of the hippocampal formation is the reduction of such interference.

Does increased interference occur during AD? Using the Stroop Color-Word Test, Fisher, Freed, and Corkin (1990) have demonstrated that, relative to normal elderly controls and as severity of dementia increases, AD patients display less resistance to interference. Additionally, using the California Verbal Learning Test, which provides indices of vulnerability to interference as well as intrusion and perseveration rates, Delis, et al. (1991) have demonstrated that AD patients are more vulnerable to interference than other dementia (Huntington disease) patients.

How is this increased interference manifest in normal aging and AD? Luria (1977) and Shindler, Caplan and Hier (1984) suggest that intrusion errors may be due to the inability to suppress incorrect responses. The information could be seemingly irrelevant, such as extra-list intrusion errors would appear at first glance. However, as Hebb (1976) suggests, the uninhibited information may actually be cognitively related, such as conceptually or phonologically, to the information to be recalled.

If intrusion errors are in some way related to the information to be recalled then the intrusion errors may be produced as a result of a lack of inhibition of closely related prior knowledge. Activation of related information along the lines of the spreading activation model of memory proposed by Collins and Loftus (1975) or the parallel distributed processing model of McClelland and Rumelhart (1985) allows for related concepts to be raised to higher levels of activation when the activation level for any particular concept has been previously raised.

When these related concepts are raised to higher levels of activation they must also be inhibited in some manner in order for the appropriate response to receive complete activation and, therefore, be expressed. Applying this reasoning to the production of intrusion errors suggests that these errors may be due to the inability to suppress closely related prior knowledge that is elevated to a higher level of activation and expressed as a response due to decreased inhibition.

Previous work has demonstrated that prior knowledge can interfere with the acquisition of new information (Lewis & Anderson, 1976; Peterson & Potts, 1982). Reisberg et al. (1982) report that early AD patients still possess memory for things that have been learned in the distant past. Therefore, past knowledge would be an accessible source of information to the AD patient and these patients may rely on this type of information during recall since this information may be inhibited to a lesser degree and, consequently, expressed as a response possibly due to the inability of the hippocampal formation to inhibit this type of information.

Shimamura and Squire (1984) observed that amnesics display preserved activation -- a process thought to facilitate access to preexisting representations. Since amnesics have been demonstrated to display memory deficits similar to AD patients (Butters, et al., 1987; Delis, et al., 1991; Meudell et al. 1978; Winocur & Weiskrantz, 1976) possibly due to similar underlying structural abnormalities (Jernigan et al. 1991) it would be parsimonious to assume that the process of activation is similarly preserved in AD.

When assessing the easy or related pairs during a paired-associate learning task, the same criteria used for assessing activation in amnesics by Shimamura and Squire (1984), Morris et al. (1991) demonstrated no significant difference between normal elderly controls and very mild AD patients. This finding indicates that at least in the very early stage of AD these patients display preserved activation, (that is, they have access to preexisting memories which would allow for the possibility of previously learned material to intrude upon new material).

In addition to semantic relationships being responsible for the production of intrusion errors, phonological relationships may also be responsible for the production of intrusion errors. During the recall of letters from lists, Conrad (1962, 1964) has demonstrated that participants between 16 and 60 years of age had a tendency to produce erroneous responses that were phonologically similar to the correct letter to be recalled. Similarly, Wickelgren (1965) has demonstrated that intrusion errors based on auditory features were more likely to occur in young participants when the items to be recalled have a greater potential number of acoustically similar items that may be produced as a response.

Analysis of intrusion errors in the dissertation work of Mackell (1993) suggests that a number of extra-list intrusion errors produced by AD patients were phonologically similar to words in the list of items to be recalled. Therefore, one could infer that at least some of these extra-list intrusion errors may be produced as a result of interference on the part of phonologically similar information.

In summary, since (a) the hippocampal formation becomes increasingly atrophic with advancing age (Golomb, et al., 1993; 1994) as well as being one of the earliest areas of the brain to be affected in AD (de Leon, George, Stylopoulos, Smith, & Miller, 1989; de Leon, et al., 1993; Hyman et al. 1984), (b) the proposed role of the hippocampal formation is to reduce interference by providing increased amounts of inhibition (Olton & Shapiro, 1992; Nadel, 1992), (c) it has been postulated that intrusion errors may be produced by a lack of inhibition (Hebb, 1976), (d) AD patients have been demonstrated to produce higher frequencies of intrusion errors than other groups (Butters, et al., 1987; Bondi, et al., 1994), and (e) elderly and AD patients have access to prior knowledge which may be related to the information to be recalled (Morris et al., 1991; Reisberg et al., 1982), it would seem reasonable to suggest that intrusion errors produced during normal aging and early AD may be due to deficits in the hippocampal formation which lead to an inability to inhibit or suppress related yet irrelevant information.

Anatomical Evidence for the Localization of Different Types of Intrusion Errors

Perseveration.

Moscovitch and Winocur (1992) suggest frontal lobe damage as possibly being responsible for many of the memory deficits associated with normal aging. Since perseveration has been shown to be prevalent in patients that possess frontal lobe lesions (Anderson, Jones, Tranel, Tranel, & Damasio, 1990; Milner, 1963), it might be reasonable to expect a higher frequency of perseveration in the normal elderly than in the young if the Moscovitch and Winocur (1992) postulate of frontal lobe damage as being responsible for age associated memory impairment is valid.

Extra-list intrusion errors.

Jernigan et al. (1991) have demonstrated that amnesics possess damage to the hippocampal formation, the area of the brain implicated as being responsible for the early deficits observed in AD. In their studies of amnesic populations Butters, et al. (1987), Delis et al. (1991), Meudell, Butters, and Montgomery (1978) and Winocur and Weiskrantz (1976) have demonstrated numerous intrusion errors. The results of studies with AD and amnesic populations, taken together, suggest that intrusion errors may be associated with damage to the hippocampal formation.

As mentioned previously, the hippocampal formation is currently thought to play a significant role in the acquisition and retention of new information (Cohen & Eichenbaum, 1993; Eichenbaum et al. 1989; Squire, 1992a; Squire, 1992b; Squire, et al., 1992; Squire & Zola-Morgan, 1991) and has been demonstrated to be the earliest area of the brain to be affected in AD (de Leon et al. 1989; de Leon, et al., 1993; Hyman, 1984). Extra-list intrusion errors have been demonstrated to be prevalent in AD patients relative to young and elderly normal controls (Bondi et al., 1994; Helkala et al., 1989; Loewenstein et al., 1989; Mackell, 1993; Manning et al., in press). Since the hippocampal formation is partially disconnected from the rest of the brain in early AD, and since it has been demonstrated that these patients display extra-list intrusion errors, it would be reasonable to suggest that the production of extra-list intrusion errors in AD may be due to the hippocampal formation degeneration observed in AD.

Under all conditions, relatively few intrusion errors would be expected in the young normal controls. Previous-list intrusion errors would not be expected in the AD population, since items from the previous list should be rapidly forgotten by the AD patients.

An inability to maintain temporal order among items in a list may result in perseveration in both the elderly and AD groups. The occurrence of perseveration in the elderly and AD groups may be a result of the postulated frontal lobe dysfunction in both groups. Additionally, AD patients may produce a higher frequency of extra-list intrusion errors if extra-list intrusion errors are associated with increased hippocampal formation atrophy.

Rationale

The relationship between acoustic similarity among information to be recalled and the production of various types of intrusion errors produced by AD patients and the normal elderly population has not been previously demonstrated. Comparing the effects of phonological similarity among items within lists to be recalled in both the disease state and during the normal aging process may increase our understanding of how inhibitory processes may influence the structuring, manipulation, and retrieval of memories. Additionally, studying the various types of intrusion errors produced by these groups under conditions of phonological similarity and dissimilarity may give further support to the belief that specific types of intrusion errors are associated with distinct anatomical regions of the brain.

This study adds to previous work in the area of memory processing during aging and AD by (a) focusing on what conditions may produce intrusion errors, (b) relating different types of intrusion errors to separate anatomical regions of the brain, (c) determining if modality of presentation produces a greater effect during normal aging and early AD, and (d) by assessing the functioning of the

ALS during normal aging and during the process that leads to AD. By studying the conditions that produce intrusion errors, monitoring the types of intrusion errors produced, and correlating these findings with changes that occur in the brain, it may be possible to enhance the explanation of why or how intrusion errors are produced.

Summary of Hypotheses

1) Under all conditions, the immediate recall of early AD patients would be expected to be attenuated relative to elderly and young normal controls based on the work of Mackell (1993) and Manning et al (in press).

2) The modality effect would be expected across all groups where recall for the last item(s) following auditory presentation would be superior to recall for the last item(s) following visual presentation based on the work of Crowder and Morton (1969) and Manning et al. (1990).

3) Overall, based on the findings of Watkins et al. (1974) recall of lists composed of phonologically similar items would be likely to yield a reduced modality effect relative to recall of lists composed of phonologically dissimilar items.

4) If greater numbers of intrusion errors are produced at the end of a sequence of recalled items following visual presentation and the production of intrusion errors occurs in the order of young controls, elderly controls, mildly impaired, and early AD patients with young controls

producing the lowest and early AD patients the highest frequency of intrusion errors, then the interference hypothesis, proposed by Nairne (1988; 1990) may be supported as a possible mechanism contributing to the modality effect since, according to Nairne (1988; 1990) increased interference at the end of visually as opposed to auditorily presented lists produces impaired performance at the end of the visually presented lists.

5) If there is no difference between all the groups with respect to the modality of presentation under the numerous conditions then the Morris and Baddeley model (1988), which proposes an intact ALS and a dysfunctional CES in AD, may be supported. However, if the groups display differential performance with respect to the modality of presentation, in the order of early AD, mildly impaired, elderly controls, and young controls with the early AD group displaying the largest deficit following visual presentation and the young controls producing the least deficit following visual presentation under the numerous conditions, then the model of Manning et al. (in press) regarding the proposed locus of dysfunction being in the recoding or subvocalization process during normal aging and early AD may be supported.

6) Recall would be expected to be attenuated in all groups for lists composed of phonologically similar items relative to lists composed of phonologically dissimilar

items based on the work of Conrad & Hull (1964), Watkins et al. (1974) and Manning and Robinson (1989).

7) Elderly normal controls and AD patients should be capable of maintaining their responses within a circumscribed category of information even after the category of information presented for memorization is changed based on the work of Manning et al. (in press) and Martin and Fedio (1983).

8) Delayed recall would be expected to be attenuated in the order: young normal controls, elderly normal controls, and AD patients; where the AD patients would present the most attenuated performance and the young normal controls the least attenuated performance based on the work of Moss et al. (1986), Welsh et al. (1991) and Manning et al. (in press).

9) In general, intrusion errors, (perseveration and extra-list) would be expected to occur with greater frequency in the early AD population and to lesser degrees in the mildly impaired and elderly normal controls with the lowest frequencies expected to occur in the young normal controls based on the work of Bondi et al. (1994) ,Helkala et al. (1989), Loewenstein et al. (1989), and Manning et al. (in press).

10) In general, under conditions of phonological similarity, (which represents conditions of increased interference), increased numbers of similar sounding items,

(most likely perseveration when the lists are composed of phonologically similar items derived from a small set), would be expected to be produced in all groups relative to the recall of lists composed of phonologically dissimilar items based on the work of Conrad (1964), Baddeley (1966), Mackell (1993), and Manning et al. (in press).

11) Greater amounts of perseveration would be expected in the elderly normal control population relative to the young normal controls based on the findings of frontal lobe changes during the normal aging process (Giannakopoulos et al., 1994; Jernigan et al., 1991; Price et al., 1991) and the occurrence of perseveration in frontal lobe dysfunctional patients (Anderson et al, 1990; Corkin, 1993; Milner, 1963).

12) Since AD patients tend to possess extensive hippocampal formation atrophy and tend to have more frontal lobe degeneration, this may be a reason to expect both extra-list intrusion errors, common to individuals that possess relatively extensive hippocampal formation damage (Bondi et al., 1994; Delis et al. (1991); Helkala et al., 1989; Loewenstein et al., 1989; Mackell, 1993; Manning et al., in press), and perseveration, which occurs frequently in frontal lobe patients (Anderson et al, 1990; Corkin, 1993; Milner, 1963).

METHOD

Subjects

Subjects were selected from a population available at the New York University Medical Center's Aging and Dementia Research Center (NYUMC/ADRC). Elderly subjects were divided into three groups based on the amount of memory impairment displayed on the NYUMC/ADRC battery of memory tests, as well as the amount of functional impairment determined by psychiatric, neurologic, and medical evaluations given prior to entering this experiment.

Based on the intensive psychiatric interviews, subjects are classified according to the Global Deterioration Scale (GDS), a rating scale for dementia devised by Reisberg et al. (1982). Subjects with a GDS rating of 2 possess only subjective memory impairment and are considered normal elderly controls (GDS 2) based on their performance on a standard psychometric battery of tests and clinical assessment. In this study, the elderly control population was composed entirely of individuals with a GDS rating of 2 and MMSE scores of greater than or equal to 27.

Mildly impaired subjects, (GDS 3), possess some memory impairment based on their performance on a standard neuropsychometric battery of tests and clinical interview, but these deficits are not considered sufficient to meet the criteria for dementia. In this study, the mildly impaired group was composed of individuals with MMSE scores greater than or equal to 27. Subjects in the mild (early) stage of AD, with a GDS rating of 4, exhibit sufficient deficits and impairment of functioning to be classified as displaying probable dementia according to NINCDS-ADRDA criteria. Regarding AD patients, only those rated as being in the earliest stage of AD, (GDS 4), with a Mini Mental State Exam (MMSE) (Folstein, Folstein, & Mc Hugh, 1975) score of 27 or less, were selected as participants in this group.

Additionally, a group of young (20 to 29 years of age) normal control (YC) subjects were recruited from the population of students at NYUMC/ADRC in order to determine any differences that may reflect changes occurring during the normal aging process. All YC's were screened for gross memory abnormalities using the MMSE. Any YC participant with an MMSE score of 27 or less was excluded. A total of sixteen subjects were tested in each group (GDS 2 through 4 inclusive and young normal controls).

Stimuli and Experimental Design

All of the words used in this experiment were one syllable words with a Thorndike and Lorge (1944) rating of AA. Six words that have high phonologic similarity (CALL, BALL, FALL, TALL, WALL, HALL) and six words that have low phonologic similarity (BOOK, DOOR, ROSE, GIRL, YARD, SICK) were used in this experiment. The letters used in this experiment were chosen as to their phonological similarity based on Conrad's (1964) list of auditory confusability among letters of the alphabet. One group of six letters that have high phonologic similarity (B, P, D, C, G, T) and one group of six letters that have low phonologic similarity (J, Q, R, L, S, M) as determined by Conrad (1964), and Manning (1977) were used in this experiment.

The experiment consisted of eight conditions: visual and auditory presentation of phonologically similar and dissimilar letters and words. Each condition required the immediate serial recall of eight sequences of six words or letters. Each word or letter as well as each sequence was presented separately. Sixteen subjects from each of the groups described above were presented both visually and auditorily with fully counterbalanced lists of phonologically similar and dissimilar words and letters.

The order of presentation of each condition was administered such that the experiment formed eight balanced latin squares with the 16 subjects in each group receiving all conditions. Although the same phonologically similar and dissimilar words and letters were used for both auditory and visual presentations, within each condition, subjects received 8 randomly ordered permutations of a list composed of either six words or letters without repetition of items within each list. The experiment was counter balanced such that within each group, half the subjects received auditory presentation first with the other half receiving the visual presentation first. Within each modality half of the subjects received the phonologically similar items first and the other half received the phonologically dissimilar items first.

Apparatus and Procedure

Stimulus items were presented on a computer screen with each letter being 0.25 cm X 0.7 cm. Stimulus duration and interstimulus interval were 0.5 second each. In order to alter the modality of presentation, subjects were instructed to read the words or letters either aloud or silently to themselves. Subjects were told to remember as many words or letters as they could.

For the immediate serial recall segment the subjects were instructed that they had 20 seconds to write as many words or letters as they could remember from the preceding list in the exact order of presentation. Prior to beginning a block of trials representing one condition, each subject was given two 6-item practice trials in order to familiarize subjects with the upcoming block of trials. The practice trials did not contain the same stimuli used in the ensuing experimental trials. As a measure of delayed recall, at the end of the experiment each subject was asked to recall all of the words and letters they had seen in this experiment in any order.

RESULTS AND DISCUSSION

Group Demographic Profile

Throughout the results, statistics are reported as being significant at the .05 level, unless otherwise noted. Table 1 lists the mean age, MMSE scores, and years of education for each group. The mean MMSE scores of the YC, GDS 2, and GDS 3 groups are all relatively high and nearly identical.

A one way ANOVA on MMSE Scores produced a significant difference between groups, $\underline{F}(3, 60) = 29.60$, $\underline{MSE} = 2.43$. A Duncan Multiple Range (DMR) analysis revealed that the GDS 4 group was significantly different from all of the other groups. There was no significant difference between the YC, GDS 2, and GDS 3 groups with respect to MMSE scores, ($R_2 = 2.83$, $R_3 = 2.98$, $R_4 = 3.07$).

The difference between the GDS 4 patients and all other groups with respect to MMSE was expected since the GDS 4 group was restricted to a MMSE score of less than or equal to 27 as stated in the method section above and since AD can have an effect of reducing MMSE scores (McKhann et al., 1984). The procedure of restricting MMSE scores in the GDS 4 group is commonly performed in many studies in order to ensure that the group is representative of AD.

A one way ANOVA on Age also produced a significant difference between groups, $\underline{F}(3, 60) = 220.11$, $\underline{MSE} = 44.43$. A DMR analysis revealed that the YC group was significantly different from each of the other groups. Once again, this result was expected based on the definition of the group as stated in the method section above. The ages ranged between 20 to 29 in the YC group, 60 - 83 in the GDS 2 group, 60 - 86 in the GDS 3 group, and 64 - 88 in the GDS 4 group. Additionally, based on the DMR analysis, the GDS 3 group was significantly younger than the GDS 4 group. However, there was no significant difference between the GDS 2 and GDS 4 groups with respect to age, (R_2 = 2.83, R_3 = 2.98, R_4 = 3.07).

A one way ANOVA on Years of Education also produced a significant difference between groups, $F(3, 60) = 5.21$, $MSE = 6.73$. As can be seen in Table 1, the YC and GDS 2 groups are identical with respect to the mean number of years of education. Similarly, the GDS 3 and GDS 4 groups are virtually identical regarding the mean number of years of education. The mean number of years of education of the GDS 3 and GDS 4 groups are lower than the respective means of the YC and GDS 2 groups.

A DMR analysis of the data with respect to years of education revealed a significant difference between the YC group and the GDS 3 group, as well as a significant difference between the YC group and the GDS 4 group. Similarly, the DMR analysis displayed significant differences between the GDS 2 group and the GDS 3 group, as well as between the GDS 2 group and the GDS 4 group with respect to years of education. No significant difference was obtained between the YC group and the GDS 2 group with respect to years of education. Finally, results from the DMR analysis revealed no significant difference between the GDS 3 and GDS 4 groups with respect to years of education, (R_2 = 2.83, R_3 = 2.98, R_4 = 3.07). These results suggest that years of education would not be a factor influencing any differences obtained in this study regarding normal aging; nor would years of education be a factor influencing any differences obtained regarding progression of disease from GDS 3 to GDS 4.

Effects of Aging and Disease

Correct responding during immediate serial recall was analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) x 2 (modality) x 2 (phonological similarity) x 2 (category) x 6 (serial position) ANOVA was used to analyze correct responding during immediate serial recall. See the Appendix for a Table that displays all the means underlying the five way interaction in this ANOVA.

The ANOVA revealed a significant main effect of group, $F(3, 60) = 33.45$, $MSE = 53.94$. Over all conditions, the mean number correct for each of the four groups from the best to the worst performance was: YC (6.63), GDS 2 (4.73), GDS 3 (3.71), and GDS 4 (3.14), see Figure 1. Results of a

DMR test performed on the group means revealed significant differences between the YC group and each of the other groups, the GDS 2 group and each of the other groups. No other comparisons were reliable, (R_2 = 0.74, R_3 = 0.77, R_4 = 0.80). The GDS 3 and GDS 4 groups did not display significant differences.

Serial Position Effects

Upon initial inspection of the Table in the Appendix, the serial position curves obtained in the current study appear to be slightly flattened relative to the traditional concept of serial position curves frequently obtained in previous studies. In order to examine this discrepancy, a substantial part of the discussion that follows pertains to the serial position curves in the YC group. See Table 2 for a comparison of the serial position curves obtained in the present study with serial position curves obtained under similar conditions in previous studies.

Of the studies presented in the Table 2, Watkins et al. (1974) studied serial recall of phonologically similar and dissimilar words, Crowder (1978) studied serial recall of phonologically distinct yet similar words and phonologically identical words (homophones), and Manning and Greenhut-Wertz (1990) and Manning et al. (in press) studied serial recall of phonologically dissimilar letters. Each of the studies referred to in Table 2 used lists of six items, except for Watkins et al (1974) and Crowder (1978) who used lists of seven items. All of the subjects in the studies referred to in Table 2 were young controls.

Regarding auditory presentation of phonologically dissimilar words, the strongest primacy and recency as well as the most "U" shaped curve was obtained in the Watkins et al. (1974) study (see Table 2). The present study obtained less recency and lower error rates across all serial positions producing a "flatter" serial position curve than the Watkins et al. (1974) study (see Table 2).

One possible reason that the lower error rates were generated across all serial positions in the present study may pertain to task difficulty. Recall of the six phonologically dissimilar words in the present study may not have been as difficult as the recall of the seven phonologically dissimilar words in the Watkins et al. (1974) study. Inspection of the curves for auditorily presented, phonologically dissimilar words reveals that the performance approached ceiling in the present study.

Regarding the visual presentation of phonologically dissimilar words, the Watkins et al. (1974) results produced stronger primacy and recency in addition to generating a more "U" shaped serial position curve overall relative to the results of the present study (see Table 2). Once again, presence of a more traditional serial position curve in the Watkins et al. (1974) study may have been due to the longer list length in the Watkins et al. (1974) study.

Additionally, the Watkins et al. (1974) study did not repeat items across conditions which may also account for the presence of a more "U" shaped curve in their study. In the present study, the same items were used for presentation in both modalities which could also account for overall better recall and "flatter" curves in the current study.

It is important to note, however, that in both the Watkins et al. (1974) study and in the present study the recency portion of the serial position curve decreased following visual presentation relative to the recency portion of the serial position curve following auditory presentation (see Table 2). This demonstrates that a strong modality effect was obtained by Watkins et al. (1974) and an attenuated modality effect was obtained in the present study under these conditions.

Following the auditory presentation of phonologically similar words, all of the cited studies, including the present study, obtained approximately equivalent primacy effects (see Table 2). The strongest primacy and recency effects were obtained by Watkins et al. (1974). In the present study, recency more closely resembled the recency obtained in the Crowder (1978) study (see Table 2). Similarly, the overall shape of the curve obtained in the present study more closely resembles the curve obtained by Crowder (1978) than the shape of the curve obtained in the Watkins et al. (1974) study.

The weakened recency and the overall flattened curve obtained in the present study which produces results that are more similar to the Crowder (1978) study than to the Watkins et al. (1974) study may be due to the nature of the stimuli used in the various studies. The phonologically similar words used in the present study had variable initial consonants with similar vowel sounds and final consonants between words, for example, ball, call, wall. The Crowder (1978) study used words with similar initial consonants, variable vowel sounds, and similar final consonants between words, for example, tees, toes, ties. The Watkins et al. (1974) study employed words having similar initial consonants and vowel sounds but the final consonant was variable between words, for example, cod, cob, cog.

Higher error rates producing a more "U" shaped curve in the Watkins et al. (1974) study may have been due to greater difficulty in remembering the variable final consonant as opposed to remembering the variable initial consonants in the present study and the variable vowel sound of the Crowder (1978) study. The present study and the Crowder (1978) study may produce similar results because the initial consonant and the immediately preceding vowel sound may be associated together and these words may be more easily recalled than words having similar initial consonants and vowel sounds but different final consonants between them as in the Watkins et al. (1974) study. Using lists of nonwords in which the initial consonant varied and the vowel sound remained constant, similar to the stimuli used in the present study, Crowder (1971) obtained curves that were flattened and had attenuated recency relative to the curves obtained in the Watkins et al. (1974) study.

An alternate explanation for similarities between the Crowder (1971; 1978) studies and the present study involves the frequency of presentation of stimulus items. Crowder (1971; 1978) and the present study used similar stimulus items for presentation under the different modality conditions. Therefore, the additional exposure to the same stimulus items may account for an overall improved performance and "flatter" curves in both the Crowder (1971; 1978) studies and in the present study. Lack of repeated exposure to the same stimulus material across modalities may account for the more characteristic "U" shaped curves obtained in the Watkins et al. (1974) study.

It is also important to note that in all of the studies presented in Table 2 in which there are serial position curves for the auditory presentation of both phonologically similar and dissimilar words, percent error is increased following the presentation of phonologically similar words across all serial positions. This demonstrates that each of the studies, Watkins et al. (1974), Crowder (1978), and the present study, obtained a phonological similarity effect.

Following the visual presentation of phonologically similar words, Watkins et al. (1974) obtained the strongest primacy, strongest recency, and the most "U" shaped curves of the three studies compared (see Table 2). Once again, the present study obtained a curve similar in shape to the Crowder (1978) study. The recency obtained following visual presentation of phonologically similar words by Watkins et al. (1974) was attenuated from the recency obtained following auditory presentation of phonologically similar words. In both the present study and the Crowder (1978) study there was a complete loss of recency along with an overall flattening of the serial position curve. As mentioned previously, these differences between studies may be due to a linkage between the start consonant and the vowel sound in both the Crowder (1978) study and the present study.

Turning to the auditory presentation of phonologically dissimilar letters, the serial position curves obtained in the three studies compared in Table 2 bear striking resemblances. Manning and Greenhut-Wertz (1990) and Manning et al. (in press) obtained only slightly stronger primacy than the current study. Additionally, the curves for each of the studies appear to be somewhat flattened and recency appears to be weak in all of the studies, the strongest recency being obtained in the Manning and Greenhut-Wertz (1990) study. The similarity among the studies is not surprising since the stimuli and conditions among the studies were nearly identical.

Regarding the visual presentation of phonologically dissimilar letters, the curves obtained in all three studies compared in Table 2 appear similar. The Manning and Greenhut-Wertz (1990) and Manning et al. (in press) studies obtained slightly stronger recency than the current study. Additionally, the curve obtained in the present study appears much more flattened than the other studies. The flattened curve obtained in the present study appears to be due to a ceiling effect. Across all the serial positions the greatest percent error was 0.06, indicating that the task was too easy for this group of subjects.

It is also important to note that of the three studies compared in Table 2 that contain both auditory and visual presentations of phonologically dissimilar letters, all three studies obtained larger error percents at the last two serial positions following visual presentation relative to auditory presentation representing a modality effect. The auditory and visual presentations of phonologically similar letters in the present study were not compared to other previous studies due to a lack of previous recall studies that employed these conditions.

The remainder of the discussion in this section pertains to the serial position curves and effects in all of the groups in the present study. In relation to serial position effects, the ANOVA also demonstrated a significant main effect of serial position, $F(5, 300) = 63.84$, $MSE = 4.44$. The main effect of serial position reflects the primacy and recency effects across all groups and conditions as well as a variety of changes in shape in the overall serial position curve. As mentioned previously, the serial position curves for each group under the various conditions are shown in the Table in the Appendix.

Examination of the significant interaction of Group x Serial Position, $F(15, 300) = 3.71$, $MSE = 4.44$, demonstrates effects of serial position along with effects of aging and disease. See Table 3 for a summary of correct responding during immediate serial recall as a function of serial position and group. As age and disease increases, greater attenuation of the serial position curve was observed, see also Figure 2.

Increased attenuation of the serial position curve with age and disease supports the findings of Shimamura et al. (1990) who demonstrated an inability on the part of frontal lobe patients to organize information temporally. Increased attenuation of the serial position curve in the current study suggests at least a partial inability on the part of the GDS 2's, GDS 3's, and GDS 4's to maintain temporal order. The inability to maintain temporal order may be due to frontal lobe abnormalities or changes as suggested by Corkin (1993) and Moscovitch and Winocur (1992).

The presence of recency was determined by conducting matched, one tailed, t tests between correct recall at position 5 and position 6 for each group under each condition. One tailed t tests were used due to the directional nature of the hypothesis being tested: performance at serial position 6 would be superior to performance at serial position 5. Table 4 displays the results of the matched t tests between positions 5 and 6 for each group under each condition. The majority of the tests demonstrate superior recall at position 6. Significance at the 0.05 level or marginal significance at the 0.10 level was achieved in 19 out of the 32 comparisons.

In Table 4 it can be seen that the YC's demonstrated recency in all of the auditory conditions. Following visual presentations the YC's produced recency with marginal significance only with phonologically dissimilar letters and words. As can be seen in Table 2, an attenuated form of recency has been obtained following the visual presentation of phonologically dissimilar words in the Watkins et al. (1974) study. Following the auditory and visual presentations of phonologically dissimilar letters, attenuated recency was obtained in the Manning and Greenhut-Wertz (1990), and Manning et al. (in press) studies (see Table 2).

Similarly, the GDS 2's displayed recency in all of the auditory conditions. Also, similar to the YC group, the GDS

2 group displayed recency following the visual presentation of phonologically dissimilar letters and words. As mentioned previously, this result is not uncommon for a control group. The GDS 2 group also displayed recency following the visual presentation of phonologically similar letters and a loss of recency following visual presentation of phonologically similar words. As can be seen in Table 2, the Crowder (1978) study also produced a loss of recency following the visual presentation of phonologically similar words.

Table 4 also displays recency for the GDS 3 group in all of the auditory conditions. Similar to the GDS 2 group, the GDS 3 group also displayed recency following the visual presentation of phonologically similar letters. As mentioned previously, a weakened form of recency has been obtained in a control group under similar conditions. Regarding the GDS 4 group, recency was obtained only following the auditory presentation of phonologically similar letters, although the results were in the correct direction.

The elimination of recency was observed for all groups in the present study during the immediate recall of visually presented phonologically similar words. Under similar conditions, Crowder (1978) obtained a loss of recency in controls and Watkins et al. (1974) obtained an attenuated form of recency relative to recall of auditorily presented phonologically similar words (see Table 2). The loss of recency following visual presentations in the GDS 3 group and following both auditory and visual presentations in the GDS 4 group would presumably be due to the detrimental effects of the disease upon recall. Disease may be implicated over aging effects since the GDS 2 group, subject to aging effects, displays recency following all auditory and most visual presentations.

Modality Effect

There was no significant main effect of modality. This may be due to the inclusion of other factors in the ANOVA which may have diminished any overall modality differences. The significant interaction of Modality x Serial Position, $F(5, 300) = 19.88$, $p < .01$, $MSE = 2.45$, reflects a modality effect of superior recall for the latter item(s) from the lists following auditory presentation across all groups.

Table 5 presents the results of matched, one tailed, t tests on correct recall at position 6 between auditory and visual presentations for each group under all conditions. One tailed t tests were used due to the directional nature of the hypothesis being tested: performance for final list items presented auditorily would be superior to performance for final list items presented visually. As expected, auditory performance was superior to visual performance in almost all of the conditions, with the exceptions of phonologically similar and dissimilar words in the YC group, and phonologically similar letters in the GDS 4 group (see

Table 5).

Following presentations of phonologically similar and dissimilar words, the lack of a modality effect in the YC group may have been due to the weakened recency obtained in the auditory conditions. Regarding the visual presentation of phonologically dissimilar words, recency was attenuated from the auditory condition in the present study, see Table 2. Therefore, although the difference was in the correct direction, the difference between the auditory and visual conditions was not large enough to produce a significant difference.

Following the visual presentation of phonologically similar words, there was a complete loss of recency in the current study, see Table 2. In the present study, for the YC group the difference between modalities following the presentation of phonologically similar words was approximately equivalent to the difference between modalities following the presentation of phonologically similar words obtained by Crowder (1978) (see Table 2). As mentioned previously and as similar to the current study, Crowder (1971) demonstrated an elimination of the modality effect when vowels were held constant and the consonants varied in nonwords. Therefore, based on the work of Crowder (1971), the modality effect should be eliminated under these conditions.

Watkins et al. (1974) demonstrated that the presence of phonologically similar items within a list considerably reduces the size of the modality effect. Overall, the results from this study support the findings of Watkins et al. (1974) regarding the reduction of the modality effect following the presentation of phonologically similar items. With the exceptions of the YC and GDS 2 groups during recall of phonologically similar letters, when significant $\underline{t}$ values representing a modality effect were obtained under conditions of phonological similarity, only marginal significance at the 0.10 level was achieved, (see Table 5).

The ANOVA produced a significant interaction of Modality x Phonological Similarity, $\underline{F}(1, 60) = 12.86$, $\underline{p} < .01$, $\underline{MSE} = 3.23$. The only means demonstrating significant pairwise comparisons based on the results of a DMR test were auditory and visual dissimilar presentations ($\underline{M}$'s = 5.33, 5.07 respectively) versus auditory and visual similar presentations ($\underline{M}$'s = 3.80, 4.00 respectively), ($R_2 = 0.37$, $R_3 = 0.39$, $R_4 = 0.40$). Although the auditory dissimilar presentation mean was greater than the visual dissimilar presentation mean and the visual similar presentation mean was greater than the auditory similar presentation mean, these differences were not significant based on the DMR test. The interaction was due to the shift from auditory superiority for phonologically dissimilar items to visual superiority for phonologically similar items.

The ANOVA also demonstrated a significant three-way interaction of Modality x Phonological Similarity x Category, $\underline{F}(1, 60) = 5.72$, $\underline{MSE} = 3.20$. See Table 6 for a comparison of the means for correct recall during immediate serial recall as a function of modality, phonological similarity and category.

As can be seen in Table 6, letters always produced superior recall in comparison to words, and phonological dissimilar items always produced superior recall relative to phonologically similar items (see below). The combination of phonological dissimilarity and letters produced the best recall. Regarding modality of presentation, visual presentation produced superior recall of phonologically similar items, conversely, auditory presentation produced superior recall of phonologically dissimilar items across all groups. Finally, the significant three-way interaction was, once again, due to the shift from auditory superiority for phonologically dissimilar items to visual superiority for phonologically similar items.

Phonological Similarity Effect

Additionally, the ANOVA revealed a significant main effect of phonological similarity, $\underline{F}(1, 60) = 132.74$, $\underline{MSE} = 9.78$, which was due to the superior recall of phonologically dissimilar items ($\underline{M} = 5.20$) relative to the recall of phonologically similar items ($\underline{M} = 3.90$). The phonological similarity effect has been demonstrated to occur throughout normal aging (Baddeley et al., 1984; Conrad & Hull, 1964), as well as during AD (Morris, 1984).

The significant two-way interaction of Group x Phonological Similarity, $F(3, 60) = 2.72$, $MSE = 9.78$, demonstrates that the combination of phonological similarity and aging exerts detrimental effects on immediate serial recall. Table 7 displays the mean number correct during immediate serial recall as a function of group and phonological similarity. As demonstrated in Table 7, phonological similarity decreases performance in the YC group, while the combination of age and phonological similarity decreases performance even further, see also Figure 3.

Results of a one way ANOVA on the mean difference scores between phonologically similar and dissimilar conditions produced a significant difference between groups $F(3, 60) = 2.73$, $MSE = 0.82$, see Table 7 for the mean difference scores between phonologically similar and dissimilar conditions as a function of Group. Results of a DMR analysis on the mean difference scores between phonologically similar and dissimilar conditions produced a significant difference only between the YC group and each of the other groups, ($R_2 = 0.64$, $R_3 = 0.67$, $R_4 = 0.69$). No other pairwise comparisons were significant. This result demonstrates that the combination of age and phonological similarity has a detrimental effect on immediate serial recall with no further influence due to disease. Examination of the percent decrease due to phonological similarity reveals slightly larger differences between each of the elderly groups, see Table 7.

With respect to the phonological similarity effect, the results of this study support the finding of Morris (1984) who demonstrated that phonological similarity among items to be recalled reduced memory to the same extent in both AD patients and elderly controls. Table 7 clearly demonstrates equivalent reductions in immediate recall due to phonological similarity between the GDS 2 and GDS 4 groups. However, although the current study supports the finding of Morris (1984) regarding equivalent reductions in recall between elderly and AD patients due to phonological similarity, the current study does not support the conclusion of Morris (1984) and Morris and Baddeley (1988) regarding the intact status of the ALS in AD patients.

As mentioned in the introduction, Morris and Baddeley (1988) conclude that the ALS of early AD patients is intact based on the finding of Morris (1984) who demonstrated no difference between AD patients and elderly controls with respect to the phonological similarity effect. The underlying assumption of the Morris and Baddeley (1988) conclusion was that the ALS of the elderly controls was intact.

Based on the mean difference scores displayed in Table 7, as well as on the results of the DMR analysis, the YC group displayed less of an attenuation due to phonological similarity than the GDS 2, GDS 3, and GDS 4 groups; while the elderly groups failed to demonstrate differences among groups in relation to the mean differences. Therefore, the current study demonstrates an accentuated phonological similarity effect with increasing age and no further changes with the onset of disease, suggesting an aging deficit in the ALS and no further deficit in the ALS with the onset of disease, concurrent with the Morris (1984) finding.

Category Effects

The ANOVA revealed a significant main effect of category, $F(1, 60) = 66.65$, $p < .01$, $MSE = 8.24$. Overall, the main effect of category was due to superior recall for letters ($M = 4.97$) as opposed to words ($M = 4.13$), see Figure 4.

Prior to the present study, very few studies have been designed in which the recall of letters and words were both incorporated into the same experiment or series of experiments. Those few studies that have incorporated the recall of both letters and words into the same experiment or series of experiments do not provide or allow for a direct comparison of letters versus words from their data since they were not interested in the comparison of the recall between letters and words.

A comparison of the present study's results with similar conditions in other studies provides a contrast between the recall of words and letters, see Table 2. Over all experiments, when comparing complementary conditions, for example, auditory dissimilar letters versus words, error rates at each serial position are virtually always lower during the recall of letters as compared to the error rates at the identical serial position produced during the recall of words.

Superior recall of letters relative to words may be due to an effect first demonstrated by Baddeley, Thomson, and Buchanan (1975) and subsequently labeled as the word length effect. According to Baddeley (1994) the word length effect is the systematic decline of the immediate memory span that occurs as the spoken duration of the items to be remembered increases. Baddeley (1994) interprets the word length effect as the result of a subvocal rehearsal mechanism which is constrained by the amount of time taken to internally repeat each stimulus item. Therefore, in the present study, letters may be recalled better than words because, in general, it takes longer to subvocally rehearse the words, thereby producing poorer recall for the words relative to recall for the letters which generally take less time to rehearse subvocally.

The results of the present study also demonstrate that the ability to maintain responses within a circumscribed category, such as letters or words, was maintained throughout normal aging and early AD. This was demonstrated by a complete lack of extra-categorical intrusion errors across all groups supporting the findings of Manning et al. (in press). Under no condition did any group produce letters as responses for words to be recalled and, conversely, there were no conditions during which any group produced words as responses for letters to be recalled.

This study also supports previous findings which demonstrate that knowledge about category membership is preserved throughout normal aging and during early AD, (Bayles, Tomoeda, & Trosset, 1990; Bayles, et al., 1989; Cronin-Golomb, Keane, Kokodis, Corkin, & Growdon, 1992; Hart, Smith, & Swash, 1988; Nebes, Boller, & Holland, 1986; Nebes & Brady, 1988; 1990; Manning et al., in press; Martin & Fedio, 1983). Additionally, this study demonstrates that aging individuals and early AD patients are capable of maintaining their responses within a circumscribed category of information even after the category of information presented for memorization has been changed.

Intrusion Errors

See Table 8 for the mean number of intrusion errors produced during immediate serial recall as a function of group across all conditions. Mean number of intrusion errors for each group were calculated by summing each type of intrusion error across all serial positions and conditions for each subject and dividing by the number of subjects in each group. Among all groups, GDS 4 patients display the largest mean numbers of perseveration, extra-list, and previous-list intrusion errors during immediate serial recall.

Perseveration

Perseveration during immediate serial recall was also analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (phonological similarity) X 2 (category) X 2 (modality) X 6 (serial position) ANOVA was used to analyze perseveration during immediate serial recall.

The ANOVA revealed a significant main effect of group, $\underline{F}(3, 60) = 5.63$, $\underline{MSE} = 3.46$. Overall, the GDS 4 group produced more perseverations than any of the other groups (see Table 8). Results of a DMR analysis of the means produced significant pairwise comparisons between the GDS 4 group and each of the other groups, as well as between the YC group and each of the other groups, ($R_2 = 0.65$, $R_3 = 0.69$, $R_4 = 0.71$). No other significant pairwise comparisons were obtained between groups.

The ANOVA also demonstrated a significant interaction of Phonological Similarity x Modality of Presentation, $\underline{F}(1, 60) = 6.66$, $\underline{MSE} = 0.31$. Results of a DMR analysis upon the means demonstrated more perseveration following auditory presentation of phonologically similar items ($\underline{M}$ = 1.26) than following the auditory or visual presentation of phonologically dissimilar items ($\underline{M}$'s = 0.42, 0.48 respectively), as well as the visual presentation of phonologically similar items ($\underline{M}$ = 1.02). In addition, the DMR analysis revealed more perseveration following the visual presentation of phonologically similar items relative to perseveration following both auditory and visual presentations of phonologically dissimilar items, (R_2 = 0.20, R_3 = 0.21, R_4 = 0.22). There were no other significant pairwise comparisons.

Additionally, the ANOVA demonstrated a significant main effect for serial position, $\underline{F}(5, 300) = 20.09$, $\underline{MSE} = 0.86$. See Table 9 for the mean numbers of perseverations at serial positions 1 through 6 over all groups and conditions. Results of a DMR analysis of the means revealed significant differences between all pairwise comparisons of the serial position means with the exception of the comparison between serial position 2 and serial position 3, (R_2 = 0.33, R_3 = 0.35, R_4 = 0.36, R_5 = 0.37, R_6 = 0.38).

These results generally support the findings of Manning et al. (in press) which indicated greater numbers of intrusion errors at the latter serial positions following immediate serial recall. Latter items in a list of items to be recalled may be more prone to interference and, therefore, intrusion errors may result. These intrusion errors would take the form of perseveration in this condition due to the greater confusability of the similar sounding items (Conrad, 1964) and the relatively small set of high frequency, similar sounding items would preclude extra-list items that were similar on the basis of sound.

The significant interaction of Group x Serial Position, $F(15, 300) = 4.42$, $MSE = 0.86$, demonstrated relatively more perseveration at the latter serial positions for the more impaired groups. Table 9 displays the mean amount of perseveration during immediate serial recall as a function of serial position and group. As the amount of impairment increases, the number of perseverations at the end of the sequence recalled increases.

The ANOVA also demonstrated a significant main effect of phonological similarity, $F(1, 60) = 44.56$, $MSE = 0.88$. Across all groups, more perseveration was produced in the lists containing phonologically similar items ($M = 2.28$) relative to lists containing phonologically dissimilar items ($M = 0.90$). The finding of more perseveration in the lists containing phonologically similar items supports previous work investigating the role of phonological similarity in the recall of items from lists (Baddeley, 1968; Conrad, 1962; 1964; Wickelgren, 1965).

The results from this study support the proposed auditory characteristic of the storage system (Baddeley, 1968; Conrad, 1962; 1964). Therefore, phonological similarity among items in the list to be recalled may create more confusion among the items to be recalled. Increased confusion among the items to be recalled may lead to an inability to maintain the temporal order of the items and, therefore, repetition of an item or items may result.

The significant interaction of Group x Phonological Similarity, $\underline{F}(3, 60) = 3.16$, $\underline{MSE} = 0.88$, indicates a difference between phonologically similar and dissimilar items within each group. The mean numbers of perseveration following the presentation of phonologically similar and dissimilar items in each group were: YC's (3.60, 1.20), GDS 2's (8.40, 3.36), GDS 3's (7.92, 2.88), GDS 4's (16.32, 6.96), respectively. Therefore, overall, phonological similarity and increased impairment results in greater numbers of perseverations.

The results of a DMR analysis of the means revealed greater numbers of perseverations in the GDS 4 patients following the presentation of phonologically similar items than in each of the other groups under all conditions, including the GDS 4 group following the presentation of phonologically dissimilar items. In addition, the DMR analysis revealed greater numbers of perseverations following the presentation of phonologically similar items in the GDS 2 group relative to each of the other groups under all conditions except following the presentation of phonologically similar items in the GDS 3 group.

Also following the presentation of phonologically similar items, the GDS 3 group produced more perseveration than the YC, GDS 2, and GDS 3 groups following the presentation of phonologically dissimilar items and more perseveration than the YC group following the presentation of phonologically similar items. Following the presentation of phonologically dissimilar items, the GDS 4 group produced more perseveration than the YC, GDS 2, and GDS 3 groups following the presentation of phonologically dissimilar items and more perseveration than the YC group following the presentation of phonologically similar items in the YC group. Following the presentation of phonologically similar items, the YC group produced more perseveration than the YC and GDS 3 groups following the presentation of phonologically dissimilar items. Finally Following the presentation of phonologically dissimilar items, the GDS 2 and GDS 3 groups produced more perseveration than the YC group following the presentation of phonologically dissimilar items, (R_2 = 0.340, R_3 = 0.358, R_4 = 0.368, R_5 = 0.377, R_6 = 0.384, R_7 = 0.389, R_8 = 0.394). No other pairwise comparisons were significant.

The ANOVA also revealed a significant main effect of category, $\underline{F}(1, 60) = 8.76$, $\underline{MSE} = 0.78$. Across groups greater mean numbers of perseverations were obtained during the immediate serial recall of letters ($\underline{M}$ = 1.86) than during the immediate serial recall of words ($\underline{M}$ = 1.32).

In summary, these results indicate that as impairment increases the number of perseverations increase at the latter serial positions. Phonological similarity has the tendency to increase the amount of perseveration over all groups, probably due to the proposed phonological nature of the storage system. Finally, greater amounts of perseveration were produced during the immediate recall of letters than during the recall of words.

Extra-List Intrusion Errors

Extra-list intrusion errors during immediate serial recall were also analyzed with a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (modality) X 2 (phonological similarity) X 2 (category) X 6 (serial position) ANOVA was used to analyze extra-list intrusion errors during immediate serial recall.

The ANOVA demonstrated a significant main effect of group, $F(3, 60) = 5.55$, $MSE = 0.48$. The GDS 4 group produced the most extra-list intrusion errors, followed by the GDS 3, GDS 2, and YC groups (see Table 8). The results of a DMR analysis of the means revealed significant differences between the GDS 4 group and each of the other groups, as well as between the GDS 3 group and the YC group and GDS 3 group and the GDS 2 group, ($R_2 = 0.25$, $R_3 = 0.27$, $R_4 = 0.28$). No other pairwise comparisons were significant between groups.

Previous-List Intrusion Errors

Previous-list intrusion errors during immediate serial recall were also analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (modality) X 2 (phonological similarity) X 2 (category) X 6 (serial position) ANOVA was used to analyze previous-list intrusion errors during immediate serial recall.

The ANOVA demonstrated a significant main effect of group, $F(3, 60) = 2.95$, $MSE = 0.15$. The GDS 4 group produced the most previous-list intrusion errors, followed by the GDS 3, GDS 2, and YC groups (see Table 8). A DMR test on the group means revealed significant pairwise comparisons among all group means, ($R_2 = 0.028$, $R_3 = 0.030$, $R_4 = 0.031$).

The ANOVA also revealed significant main effects of modality, $F(1, 60) = 4.42$, $MSE = 0.12$, and category, $F(1, 60) = 8.85$, $MSE = 0.12$. More previous-list intrusion errors were produced following visual presentations ($M = 0.24$) than auditory ($M = 0.12$). Also, more previous-list intrusion errors were produced during the recall of letters ($M = 0.30$) than during the recall of words ($M = 0.06$).

Intrusion Errors: Summary

Over all groups, the type of intrusion error occurring most frequently during immediate serial recall was perseveration. These perseverative errors occurred most frequently during the recall of lists composed of phonologically similar items. Regarding errors of perseveration, the order of the groups from the least to the most perseveration was: YC, GDS 2, GDS 3, and GDS 4, with the GDS 2 and GDS 3 groups producing approximately equal mean numbers of perseveration (see Table 9).

In general, the results from this study indicate that the GDS 4 group made the most perseverations throughout all conditions at the latter serial positions, however, the other groups also produced perseverations at the latter serial positions. The YC group produced the least number of perseverations over all conditions. The greatest number of perseverations produced by the YC group was following conditions of phonological similarity.

Over all, these results were expected and predicted on the basis of the Moscovitch and Winocur (1992) and Corkin (1993) predictions of increased amounts of perseveration with age and disease. Increased amounts of perseveration with age may be due at least in part to increased amounts of frontal lobe changes.

Additionally, increased amounts of perseveration during the immediate recall of phonologically similar material suggests the involvement of working memory since the rehearsal mechanism is believed to be phonologically based. Therefore, following conditions of phonological similarity, increased amounts of perseveration with age and a further increase with disease suggests an impairment to the working memory system, possibly the ALS component, with increasing age and disease.

Extra-list intrusion errors produced during immediate recall occurred most frequently in the GDS 4 group. Previous-list intrusion errors produced during immediate recall also occurred most frequently in the GDS 4 group, however, the GDS 3 group also produced previous-list intrusion errors and were indistinguishable from the GDS 4 group on this basis. Both extra-list and previous-list intrusion errors occurred most frequently at the latter serial positions, supporting the findings of Manning et al. (in press) with respect to extra-list intrusion errors.

Effects of a Brief Delay on Normal Aging and Early Alzheimer's Disease

Correct responding during delayed recall was also analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (phonological similarity) X 2 (category) ANOVA was used to analyze correct responding during delayed recall. Modality was no longer used as a variable in the delayed recall analysis since all subjects received both modalities previously and as a result it would be impossible to score a response as either auditory or visual.

The ANOVA demonstrated a significant main effect of group, $F(3, 60) = 25.81$, MSE = 5.05. The group order from the highest to the lowest overall mean number of items recalled correctly after a delay was: YC's (5.53), GDS 2's (4.28), GDS 3's (3.58), and GDS 4's (2.11), see Figure 5. A DMR analysis on the group means revealed significant pairwise comparisons between the YC and the GDS 4 groups, the YC and the GDS 3 groups, the YC and GDS 2 groups, the GDS 2 and the GDS 4 groups, and the GDS 3 and the GDS 4 groups, ($R_2 = 0.792$, $R_3 = 0.834$, $R_4 = 0.860$). All pairwise differences were significant except the comparison between the GDS 2 and GDS 3 groups. No significant interactions were obtained between variables.

The ANOVA also demonstrated a significant main effect of category, $F(1, 60) = 5.59$, MSE = 2.35. Over all groups, the mean number of words recalled correctly after a delay (4.10) was greater than the mean number of letters recalled correctly (3.65), see Figure 6. Superior recall of words during delayed recall is directly opposed to the finding in this study regarding the immediate serial recall of words and letters and is an important finding. An explanation of the superior recall of words as compared to letters during delayed recall may be based on the meaningfulness of the information to be recalled.

Meaningfulness, in terms of levels of processing, has been argued to be useful in aiding recall (Craik & Lockhart, 1972). It is thought that the words would have more meaning, and therefore could be recalled more easily, than letters. When information is retained in working memory, as a list of six items would be for immediate recall, meaningfulness may not be an efficient strategy and, therefore, may not be employed to encode and store an item in working memory. However, during delayed recall, when the information could be placed in a longer term storage, meaningfulness may be more useful since it could integrate new information into the preexisting structure of memory.

The mean number of correct responses, the proportion of correct responses, and the hit rate proportions during delayed recall are displayed in Table 10. The proportion of correct responding was determined by dividing the total number of correct responses by the total number correct plus the total number incorrect (consisting of omissions and intrusion errors). As can be seen in Table 10, the mean numbers of correct responses and the frequency of correct responding was greatest for the YC group, followed by the GDS 2, GDS 3, and GDS 4 groups. This finding partially replicates the work of Manning et al. (in press).

Manning et al. (in press) did not study a GDS 3 group and the performance in their elderly group during delayed recall was superior to the performance of the GDS 2 group in the present study. In the Manning et al. (in press) study, the mean number recalled correctly after a delay between the young and elderly groups were identical. One possible difference regarding subjects between the Manning et al. (in press) study and the present study may have produced the differences in results.

Manning et al. (in press) did not obtain GDS ratings on their elderly subjects. Therefore, the elderly controls in the present study and the elderly controls in the Manning et al. (in press) study may not be equivalent. The elderly controls in the Manning et al. (in press) study were highly educated and most were enrolled in college courses at the time of the study. These subjects may have been rated as GDS 1 subjects or their mean level of education may have exceeded the education of the GDS 2 subjects in the current study. Therefore, any comparison between these two groups must be made with some uncertainty.

The overall correct response hit rate was calculated by dividing the total number of correct responses during delayed recall by the total number of correct responses plus the total number of extra-list intrusion errors for each individual in each group. The order of the groups with respect to hit rates reveals identical hit rates between the YC and GDS 2 groups followed by the GDS 3 group with a slightly lower hit rate and finally, the GDS 4 group produced the lowest hit rate, (see Table 10).

The hit rate in the GDS 4 group, although less than the other groups, is higher than might be expected. This elevated hit rate indicates that when the GDS 4 patients do offer a response during delayed recall, it is frequently a correct response. This would suggest that some form of normal memory processing still occurs in early AD patients.

The result of a one-way ANOVA on the hit rate scores failed to produced a significant difference between groups, $\underline{F}(3, 60) = 2.36$, $\underline{MSE} = 0.004$, $\underline{p} > 0.08$. A preplanned DMR analysis on the hit rate scores revealed mean differences between the YC and the GDS 4 groups, as well as between the GDS 2 and the GDS 4 groups, ($R_2 = 0.042$, $R_3 = 0.044$, $R_4 = 0.046$). There were no other significant pairwise comparisons among the means. This result suggests that although the GDS 4 group appears to perform relatively well with respect to hit rate, their performance is not at the level of the YC and GDS 2 groups.

In addition to scoring the total number correct during delayed recall, responses were also scored in order to reflect grouping according to response classification (words and letters, phonologically similar and dissimilar). One point was given for each response that followed a similar response classification. A point was subtracted for each change that occurred in response classification. Therefore, a higher score indicates a stronger tendency to group responses.

See Table 11 regarding the grouping of responses during delayed recall. With respect to category (words and letters), the YC group produced the most grouping followed by the GDS 2 group, which was followed by the GDS 3 group, and finally, the GDS 4 group displayed the least grouping, see Figure 7. Similarly, in the grouping of responses during delayed recall by phonological similarity, the YC group also produced the most grouping, followed by the GDS 2 group, which was followed by the GDS 3 group, and finally, the GDS 4 group, once again, displayed the least grouping, see Figure 7. A comparison between the category and phonological similarity grouping scores within subject groups reveals a stronger tendency to group responses based on category (words and letters) relative to phonological similarity.

The result of a one way ANOVA using the delayed Category grouping data produced a significant difference between groups, $\underline{F}(3, 60) = 26.93$, $\underline{MSE} = 15.98$. The result of a DMR analysis revealed all pairwise comparisons among group means to be significant, ($R_2 = 2.83$, $R_3 = 2.97$, $R_4 = 3.07$). Additionally, the result of a one way ANOVA using the delayed Phonological Similarity grouping data produced a significant difference between groups, $\underline{F}(3, 60) = 14.53$, $\underline{MSE} = 18.32$. The result of a DMR analysis revealed significant pairwise comparisons between the YC group and each of the other groups, as well as between the GDS 2 group and each of the other groups, ($R_2 = 3.03$, $R_3 = 3.19$, $R_4 = 3.29$).

These results support the findings cited previously demonstrating that early AD patients maintain some ability to make use of category information. Although AD patients are capable of grouping by the categories of words and letters, their ability is clearly diminished. They are significantly different from each of the other groups in this ability in addition to displaying the most impaired performance.

This decreased ability to group information on the basis of category with increasing impairment may reflect deficits of the temporal and frontal lobes. The left temporal lobe has been implicated in the retrieval of nouns (Damasio & Tranel, 1993; Hart & Gordon, 1992) while the left frontal lobe has been proposed to be important in the retrieval of verbs (Damasio & Tranel, 1993; Mc Carthy, Blamire, Rothman, Gruetter & Shulman, 1993). Since the words in this study were comprised of both nouns and verbs proper functioning of both the temporal and frontal lobes may have been necessary to perform correctly. The pattern of results obtained, increasing impairment in grouping by category from the YC group to the AD group, supports what is known regarding atrophy in the frontal and temporal regions in each of the groups, increasing atrophy in the order of YC, GDS 2, GDS 3 and GDS 4 groups.

In relation to phonological similarity, the GDS 3 group did not differ from the GDS 4 group, suggesting the possibility of a similar detrimental process occurring in both groups. Both the GDS 3 and GDS 4 groups were significantly different from the YC and GDS 2 groups with respect to grouping by phonological similarity which suggests possible dysfunction of the phonological storage mechanism due to disease and supports previous findings regarding immediate recall in this study. Significant differences between the YC group and the GDS 2 group with respect to grouping by phonological similarity suggest detrimental effects of age upon the phonological storage mechanism of memory. This finding also supports previous findings in this study with respect to age effects upon the phonological storage mechanism during immediate recall.

Effects of a Brief Delay on the Production of Intrusion Errors

Perseveration

Perseveration during delayed recall was also analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (phonological similarity) X 2 (category) ANOVA was used to analyze perseveration during delayed recall.

The ANOVA demonstrated a significant main effect of phonological similarity, $F(1, 60) = 4.88$, $MSE = 0.14$. The mean number of perseverations during the delayed recall of phonologically similar items (0.18) was greater than the mean number of perseverations during the delayed recall of phonologically dissimilar items (0.08). This result supports the finding of increased perseveration with phonological similarity during immediate recall as mentioned previously in the present study.

The mean number of perseverations during delayed recall for all groups as a function of phonological similarity and category are presented in Table 12. No significant interactions were obtained between variables.

Extra-List Intrusion Errors

Extra-list intrusion errors during delayed recall were also analyzed using a design in which group was a between subject variable and all other variables were within subject variables. Specifically, a 4 (group) X 2 (phonological similarity) X 2 (category) ANOVA was used to analyze extra-list intrusion errors during delayed recall.

The ANOVA demonstrated a significant main effect of phonological similarity, $F(1, 60) = 16.33$, $MSE = 0.11$. Examining the significant main effect of phonological similarity revealed more extra-list intrusion errors during the recall of phonologically dissimilar items ($M = 0.16$) than during the recall of phonologically similar items ($M = 0.00$) across all groups.

The ANOVA also demonstrated a significant main effect of category, $F(1, 60) = 4.27$, $MSE = 0.11$, due to a greater mean number of extra-list intrusion errors produced during the delayed recall of letters (M = 0.13) relative to the mean number of extra-list intrusion errors produced during the delayed recall of words (M = 0.04).

The ANOVA also produced a significant interaction of Category x Phonological Similarity, $F(1, 60) = 4.27$, $MSE = 0.11$. A DMR analysis of the means revealed a greater mean number of extra-list intrusion errors during the delayed recall of phonologically dissimilar letters (M = 0.25) relative to phonologically dissimilar words and phonologically similar words and letters (M's = 0.08, 0.00, 0.00, respectively), across all groups, ($R_2 = 0.113$, $R_3 = 0.119$, $R_4 = 0.123$). No other pairwise comparisons among the means were significant.

This finding also demonstrates an interaction between phonological similarity and extra-list intrusion error. It appears that the delayed recall of phonologically dissimilar letters produces more extra-list intrusion errors than the delayed recall of phonologically dissimilar words; while phonological similarity has no effect upon the production of extra-list intrusion errors. The mean number of extra-list intrusion errors during delayed recall for all groups as a function of phonological similarity and category are presented in Table 13.

Summary and Conclusions

In general, this study provides support for previous findings regarding the function of memory during aging and

AD with respect to immediate and delayed recall and intrusion errors. Additionally, many of the predictions made in the introduction were supported. During both immediate and delayed recall the order of the groups ranging from the highest to the lowest mean number of items correct was YC, GDS 2, GDS 3, and GDS 4. Conversely, the production of intrusion errors among groups during immediate serial recall followed the reverse order of correct recall.

Modality and phonological similarity effects were maintained throughout normal aging and during early AD. Relative to normal aging, an accentuated modality effect was not obtained during early AD. The phonological similarity effect was maintained and accentuated to a similar extent in the elderly and disease groups, suggesting a possible dysfunction with age and no further dysfunction with disease. All groups were able to maintain their responses within the proper category. During immediate serial recall all groups demonstrated superior recall for lists of letters as opposed to lists of words.

Regarding intrusion errors during immediate serial recall, this study demonstrated that increased interference, represented by the condition of phonological similarity, produced increasing frequencies of intrusion errors within groups. The presence of perseveration following the presentation of phonologically similar information would suggest that working memory is affected to some degree by the changes occurring during normal aging and in early AD, since working memory is believed to be in part phonologically based and the interfering information was phonologically similar.

Additionally, results from the present study suggest an age related impairment in the ALS of working memory. This conclusion is based on the findings of (a) increased perseveration following the presentation of phonologically similar items in the elderly, (b) lack of a difference among the elderly groups with respect to the phonological similarity effect, (c) an accentuated phonological similarity effect in the elderly groups relative to the young control group, and (d) a decreased ability with age to group information on a phonological basis during delayed recall, suggest age related impairment to the ALS of working memory.

During delayed recall words were recalled better than letters, suggesting that meaningfulness may be an aid to memories that persist over longer intervals. The order of the groups performance during delayed recall was similar to the order of performance following immediate recall with diminishing performance occurring with increasing impairment. Examination of hit rates during delayed recall revealed similar hit rates in the young and elderly control groups followed by decreasing but relatively high hit rates in the more impaired groups, suggesting that some normal level of processing may remain in the impaired groups. Additionally, grouping by category and phonological similarity is maintained in the impaired groups, however, the ability decreases with increased impairment.

Finally regarding intrusion errors, early AD patients produce the largest numbers of intrusion errors of all types, however, the other groups also produce perseverations. Certain conditions also lead to different types of intrusion errors with phonological similarity producing more perseveration in all groups and phonological dissimilarity producing extra-list intrusion errors.

The interaction of phonological similarity and type of intrusion error may suggest an integration between working memory and a long term storage system since perseveration is influenced by phonological similarity and occurs mainly during immediate recall which invokes working memory while extra-list intrusion errors appear to be restricted to phonologically dissimilar items and occur during immediate and delayed recall. The other system integrated with working memory may be the hippocampal formation since the hippocampal formation is considered to be a main source of inhibition (Olton & Shapiro, 1992; Nadel, 1992).

If this view is correct then the hippocampal formation would be intimately involved with the CES in order to focus attention by providing the necessary inhibition in order to promote learning and produce memory. Therefore, another function of the CES may be to regulate the amount of inhibition via the hippocampal formation in addition to the previously described functions of coordinating multiple tasks simultaneously and maintaining temporal relationships. This study suggests a relationship between the hippocampal formation and the prefrontal cortex such that the two locations interact to form an important aspect of the working memory model: the CES.

Previous work that supports this interpretation includes that of Craik et al. (1990) who report that the CES is dysfunctional in normal aging and Morris (1984; 1994) who reports the CES is further dysfunctional in AD. Additionally, Golomb et al. (1993; 1994) demonstrate that the hippocampal formation is mildly atrophic during normal aging and de Leon et al. (1989; 1993) demonstrate that the hippocampal formation is more severely atrophic in mild cognitive impairment and mild AD.

Additionally, Brown and Zador (1990) suggest neuromodulatory control of hippocampal activity via extrinsic inputs. Insausti, Amaral, and Cowan (1987) demonstrated cortical afferent connections in the monkey from posterior orbitofrontal cortex, dorsal lateral frontal cortex, and medial frontal cortex to the entorhinal cortex which would allow for frontal control of the hippocampal formation. Finally, in a review of the literature, Weinberger (1993) suggests an executive role for the prefrontal cortex based on the connections formed between the prefrontal cortex and numerous brain regions, one of which includes the hippocampal formation.

Results from the current study do not support the view of Corkin (1993) who suggests, based on findings from both the animal and human literature of increased perseverative errors with frontal lobe damage, that working memory may be localized solely to the prefrontal cortex and that memories stored in working memory are distinct from the formation of memories laid down by the limbo-diencephalic system. Rather, the results of this study support an integration between the frontal lobes and the limbo-diencephalic system in order to produce a functional CES.

Increasing evidence is being collected which suggests that complex cognitive processing involves an integration of multiple memory systems and does not rely solely on individual neural systems (Mesulam, 1990). Although many different types of memory systems have been demonstrated or defined (see Schacter and Tulving, 1994 for a review), normal cognitive functions appears to require communication between a network of systems.

Based on the results from this study some possible directions for future research might include: (a) further investigations of the production of intrusion errors by correlating the production of specific types of intrusion errors with localized brain damage using modern imaging techniques (such as MRI and functional MRI), (b) further investigation of intrusion errors by studying other factors (such as meaning and the associative relationships between words) that may lead to increased frequencies of extra-list intrusion errors, (c) examination of interference effects by comparing performance between groups using lists comprised of both homogenous and heterogenous categories (examining proactive inhibition in young and elderly controls as well as mildly impaired and AD patients), and (d) continuing the investigation of the integrity of the ALS throughout the normal aging process in order to determine if attenuation of the ALS (specifically with regard to the articulatory subvocalization process) occurs during normal aging. Results from this study suggest that equivalence of phonological similarity effects between the elderly and AD groups may not be sufficient evidence to propose an intact ALS.

Table 1

Mean Age, MMSE Scores, and Years of Education for Each Group

	Age	MMSE	Education
YC	23.94	29.19	16.38
N = 16	(2.93)	(0.66)	(1.59)
	[20 - 29]	[28 - 30]	[14 - 19]
GDS 2	72.38	29.06	16.44
N = 16	(8.07)	(1.06)	(2.71)
	[60 - 83]	[27 - 30]	[12 - 20]
GDS 3	70.31	28.88	13.88
N = 16	(7.60)	(1.02)	(2.39)
	[60 - 86]	[27 - 30]	[10 - 18]
GDS 4	76.63	24.81	13.81
N = 16	(6.80)	(2.66)	(3.37)
	[64 - 88]	[21 - 27]	[8 - 20]

Note. Standard deviations are reported in parentheses. Ranges are reported in brackets. MMSE scores are based on a scale of 30. In all groups except the GDS 4 group subjects were required to score $\geq$ 27 on the MMSE. In the GDS 4 group subjects were required to score $\leq$ 27 on the MMSE.

Table 2

Comparison of Serial Position Curves Obtained in the Present Study with those Obtained in Previous Studies

	Serial Position					
	1	2	3	4	p	f
Auditory Dissimilar Words						
Watkins et al. (1974)	0.45	0.71	0.78	0.79	0.72	0.39
Weickert (1996)	0.15	0.23	0.20	0.23	0.22	0.13
Visual Dissimilar Words						
Watkins et al. (1974)	0.44	0.64	0.72	0.80	0.78	0.68
Weickert (1996)	0.09	0.15	0.20	0.21	0.26	0.21
Auditory Similar Words						
Watkins et al. (1974)	0.50	0.76	0.84	0.91	0.82	0.61
Crowder (1978)[a]	0.07	0.17	0.20	0.25	0.40	0.32
Weickert (1996)	0.18	0.27	0.41	0.28	0.34	0.23
Visual Similar Words						
Watkins et al. (1974)	0.45	0.64	0.78	0.87	0.86	0.74
Crowder (1978)[a]	0.12	0.22	0.21	0.30	0.57	0.57
Weickert (1996)	0.12	0.18	0.19	0.18	0.20	0.21

(table continues)

Table 2 (continued)

Comparison of Serial Position Curves Obtained in the Present Study with those Obtained in Previous Studies

	Serial Position					
	1	2	3	4	p	f
Auditory Dissimilar Letters						
Manning/Greenhut(1990)	0.02	0.12	0.19	0.16	0.12	0.03
Manning et al in press	0.01	0.14	0.19	0.08	0.09	0.05
Weickert (1996)	0.07	0.13	0.12	0.09	0.03	0.00
Visual Dissimilar Letters						
Manning/Greenhut(1990)	0.03	0.08	0.09	0.16	0.20	0.13
Manning et al in press	0.03	0.09	0.09	0.20	0.28	0.19
Weickert (1996)	0.01	0.05	0.05	0.06	0.06	0.04

Note. All values are expressed as percent error. All subjects are young controls. All authors used lists of six items except Watkins et al. (1974) and Crowder (1978) who used lists of seven items. The Watkins et al. (1974) data were estimates derived from figures. p and f = the penultimate item and the final item, respectively.

[a] Crowder's (1978) data were based on phonologically similar yet distinct items.

Table 3

Mean Number of Items Recalled Correctly during Immediate Serial Recall as a Function of Group and Serial Position

	Serial Position						
	1	2	3	4	5	6	*M*
YC	7.20	6.63	6.32	6.51	6.34	6.77	6.63
GDS 2	6.09	4.98	4.31	4.20	4.07	4.72	4.73
GDS 3	5.38	4.09	3.43	3.16	2.84	3.36	3.71
GDS 4	5.09	3.49	2.91	2.60	2.30	2.45	3.14

Note. Maximum score at each serial position is 8.00.

Table 4

Recency during Immediate Recall as shown by Matched t Tests as a Function of Group, Modality, Phonological Similarity, and Category

		Phonological Similarity		Phonological Dissimilarity	
		Letters	Words	Letters	Words
YC	Auditory	3.22**	2.39**	2.24**	2.30**
	Visual	0.32	-0.56	1.86*	1.52*
GDS 2	Auditory	3.94**	1.41*	2.44**	2.53**
	Visual	1.99**	-0.79	1.55*	2.71**
GDS 3	Auditory	3.24**	1.73*	2.52**	1.85**
	Visual	2.80**	-1.38	0.43	-0.18
GDS 4	Auditory	1.60*	0.38	1.19	0.32
	Visual	0.92	-1.82	0.57	-3.00

Note. Recency was determined by using matched *t* Tests to compare serial position 5 with serial position 6 for each group under each condition.

* at a positive value denotes a marginally significant $t(15)$, $p < 0.10$, value, cv = 1.34, indicating recency.

** at a positive value denotes a significant $t(15)$, $p < 0.05$, value, cv = 1.75, indicating recency.

Table 5

Results of Matched t tests Between Auditory and Visual Scores at Position 6 in Immediate Recall as a Function of Group, Phonological Similarity, and Category

	Phonologically Similar		Phonologically Dissimilar	
	Words	Letters	Words	Letters
YC	-0.19	3.15**	0.95	1.78**
GDS 2	1.62*	2.00**	3.06**	2.20**
GDS 3	1.60*	1.69*	2.80**	2.18**
GDS 4	1.51*	0.94	2.84**	1.83**

Note. The modality effect refers to the superior recall of the final item(s) in a sequence presented auditorily relative to visually. The modality effect was determined by using matched *t* Tests to compare correct recall at serial position 6 during auditory presentation with correct recall at serial position 6 during visual presentation for each group under each condition.

* at a positive value denotes a marginally significant $t(15)$, $p < 0.10$, value, cv = 1.34, between the auditory and visual presentation means during correct recall at position 6 indicating the presence of a modality effect.

** at a positive value denotes a significant $t(15)$, $p < 0.05$, value, cv = 1.75, between the auditory and visual presentation means during correct recall at position 6 indicating the presence of a modality effect.

Table 6

Mean Number Correct During Immediate Recall as a Function of Modality, and Phonological Similarity, and Category

		Modality	
		Auditory	Visual
Phonologically Similar			
	Words	3.60	3.97
	Letters	3.99	4.03
Phonologically Dissimilar			
	Words	4.67	4.27
	Letters	5.99	5.88

Note. Maximum score for each condition is 8.00.

Table 7

Mean Number Correct, Mean Difference and Percent Decrease between Phonological Similarity and Dissimilarity During Immediate Recall as a Function of Group and Phonological Similarity

	Phonological Dissimilarity	Phonological Similarity	D	% Decrease
YC	7.00	6.26	0.75	10.6
GDS 2	5.48	3.98	1.50	27.4
GDS 3	4.42	2.99	1.43	32.4
GDS 4	3.90	2.38	1.53	39.0

Note. Maximum score in each condition is 8.00. *D* represents the mean difference scores.

Table 8

Mean Number of Perseverations, Extra-List, and Previous-List Intrusion Errors Produced During Immediate Recall as a Function of Group

	Perseveration	Extra-List	Previous-List
YC	4.80	0.48	0.48
GDS 2	11.52	0.48	0.96
GDS 3	11.04	2.40	1.44
GDS 4	23.04	6.24	2.88

Note. These Numbers are means collapsed over all variables.

Table 9

Mean Number of Perseverations During Immediate Serial Recall as a Function of Group and Serial Position

	Serial Position						
	1	2	3	4	5	6	*M*
YC	0.48	0.72	0.80	0.88	1.36	0.56	4.80
GDS 2	0.72	1.36	1.44	2.16	3.04	3.04	11.52
GDS 3	0.40	0.72	1.20	1.52	4.16	2.88	11.04
GDS 4	0.72	1.60	1.04	4.16	8.40	7.28	23.04
M	0.56	1.12	1.12	2.16	4.24	3.44	

Table 10

Mean Number and Percent of Correct Responses and Mean Hit Rate During Delayed Recall as a Function of Group, Phonological Similarity and Category

	Phonologically Similar		Phonologically Dissimilar		Correct Recall	Hit Rate
	Words	Letters	Words	Letters	(%)	(*M*)
YC	5.63	5.38	5.81	5.31	92.19	0.99
GDS 2	5.19	4.00	3.88	4.06	71.35	0.99
GDS 3	3.88	3.38	3.69	3.38	59.64	0.97
GDS 4	2.63	1.69	2.13	2.00	35.16	0.94

Note. Maximum mean number correct at each condition is 6.00. Hit rate = Total number correct/Total number correct + Total number of extra-list intrusion errors which has a maximum score of 1.00.

Table 11

Mean Response Grouping Scores During Delayed Recall as a Function of Group, Phonological Similarity, and Category

	Category	Phonological Similarity
YC	18.56_a	13.94_a
GDS 2	12.75_b	10.06_b
GDS 3	9.81_c	6.56_c
GDS 4	6.31_d	4.69_c

Note. Category refers to words and letters, phonological similarity refers to phonologically similar and dissimilar items. Grouping scores were obtained by providing one point for each response that followed a similar classification, (words or letters, phonologically similar or dissimilar); a point was subtracted for each change that occurred in response classification. Means in the same column that do not share subscripts differ at $p < .05$ in the Duncan multiple range analysis.

Table 12

Mean Number of Perseverations During Delayed Recall as a Function of Group, Phonological Similarity, and Category

	Phonologically Similar		Phonologically Dissimilar	
	Words	Letters	Words	Letters
YC	0.00	0.00	0.24	0.24
GDS 2	0.76	1.00	0.00	0.76
GDS 3	0.52	1.24	0.24	1.00
GDS 4	1.00	1.24	0.00	0.00

Table 13

Mean Number of Extra-List Intrusion Errors During Delayed Recall as a Function of Group, Phonological Similarity, and Category

	Phonologically Similar		Phonologically Dissimilar	
	Words	Letters	Words	Letters
YC	0.00	0.00	0.00	1.24
GDS 2	0.00	0.00	0.00	0.76
GDS 3	0.00	0.00	0.52	0.76
GDS 4	0.00	0.00	0.76	1.24

Figure Caption

Figure 1. Mean number of items recalled correctly during immediate serial recall as a function of group. Maximum score for each group is 8. Performance in the YC group was significantly different from the GDS 2, GDS 3, and GDS 4 groups at $p < .05$. Performance in the GDS 2 group was significantly different from the YC, GDS 3, and GDS 4 groups at $p < .05$.

Figure 1

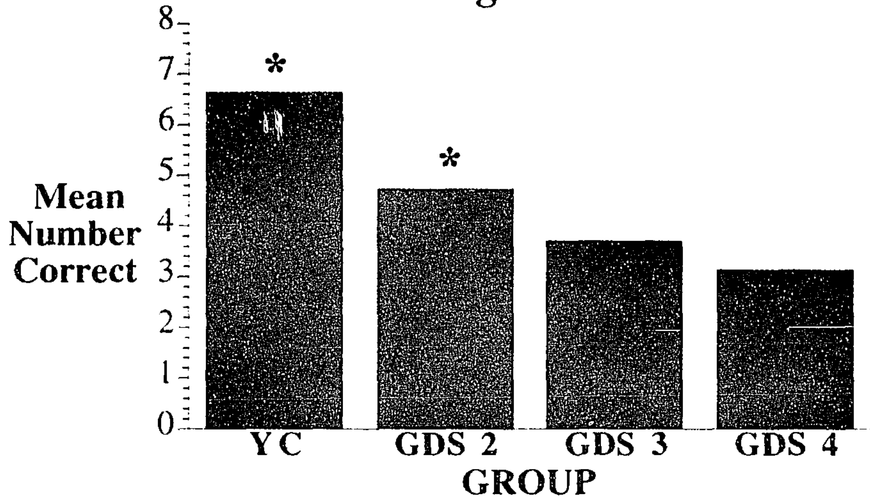


Figure Caption

Figure 2. Mean number of items recalled correctly during immediate serial recall as a function of group and serial position. Maximum score at each serial position is 8.

Figure 2

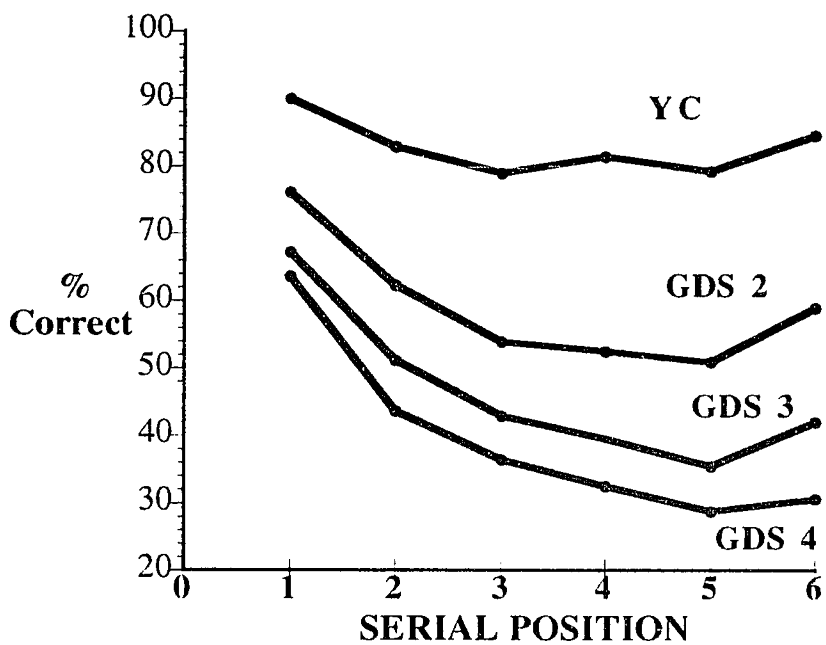
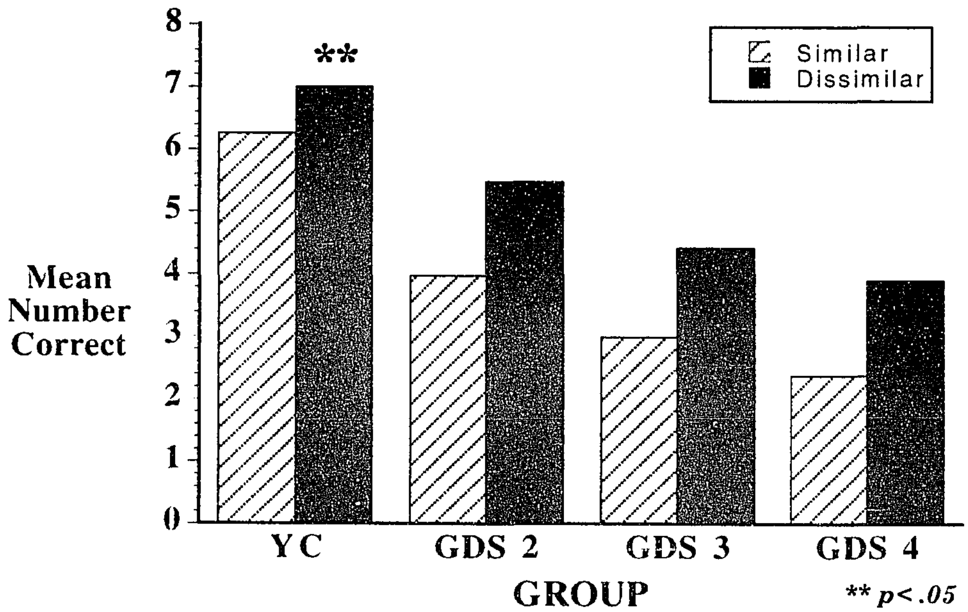

100
90
80
70
60
50
40
30
20
%
Correct
YC
GDS 2
GDS 3
GDS 4
0
1
2
3
4
5
6
SERIAL POSITION

Figure Caption

Figure 3. Mean number correct during immediate recall as a function of group and phonological similarity. Maximum score in each condition is 8. The mean difference between phonologically similar and dissimilar correct in the YC group is significantly different than the mean difference between phonologically similar and dissimilar correct in the GDS 2, GDS 3, and GDS 4 groups at $p < .05$.

Figure 3



8
7
6
5
4
3
2
1
0
Mean Number Correct
**
Similar
Dissimilar
YC
GDS 2
GDS 3
GDS 4
GROUP
** p<.05

Figure Caption

Figure 4. Mean number correct during immediate serial recall as a function of category. Maximum score in each condition is 8. Recall for letters was significantly different from recall for words at $p < .05$.

Figure 4

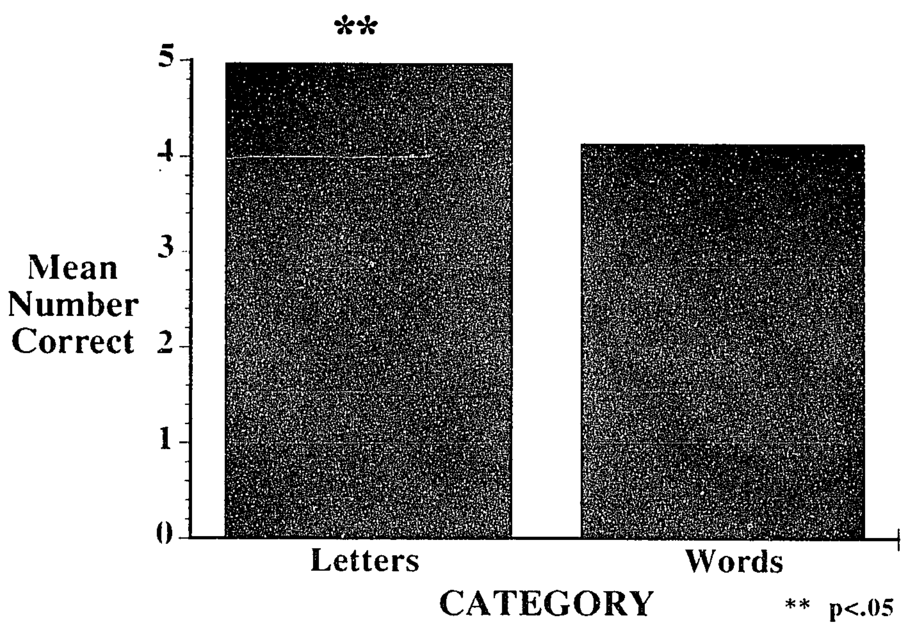


Figure Caption

Figure 5. Mean number correct during delayed recall as a function of group. Maximum score for each group is 8. Performance in the YC group was significantly different from the GDS 2, GDS 3, and GDS 4 groups at $p < .05$. Performance in the GDS 4 group was significantly different from the YC, GDS 2, and GDS 3 groups at $p < .05$.

Figure 5

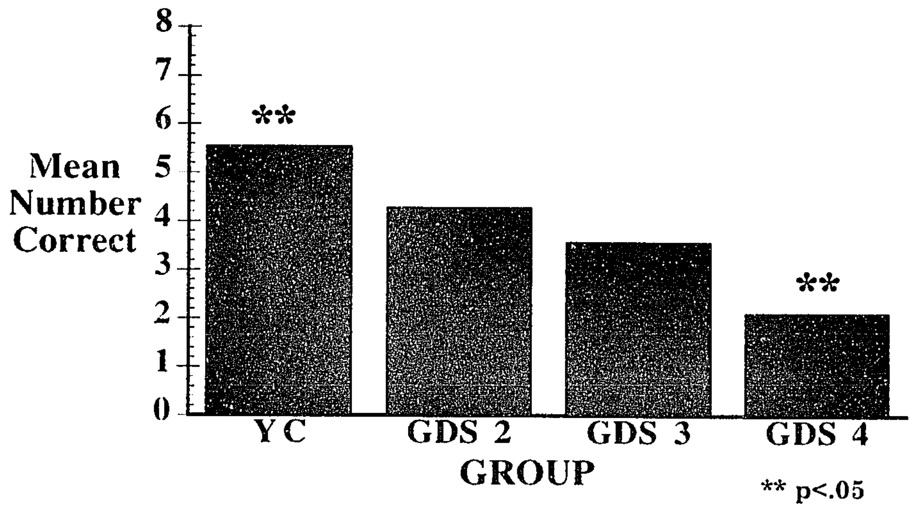


Figure Caption

Figure 6. Mean number correct during delayed recall as a function of category. Maximum score in each condition is 8. Recall for words was significantly different from recall for letters at $p < .05$.

Figure 6

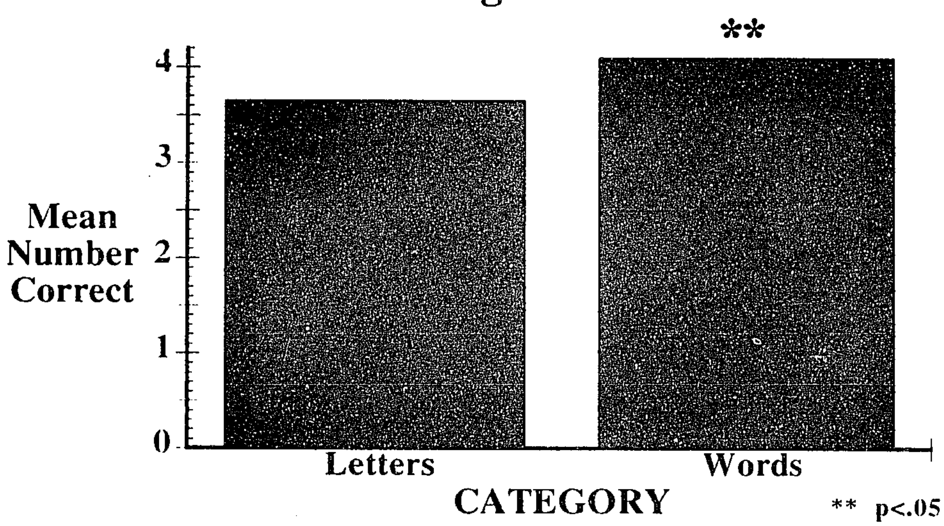
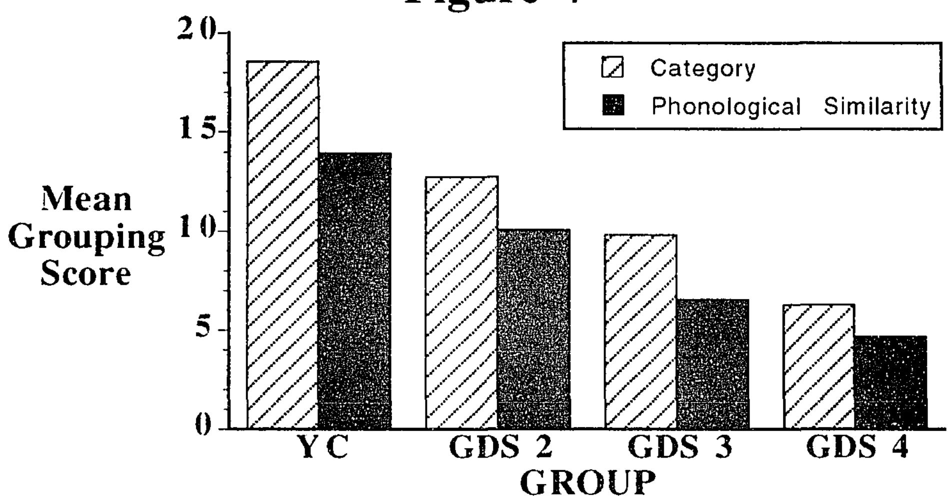


Figure Caption

Figure 7. Delayed grouping scores as a function of group, category, and phonological similarity. With respect to category (words and letters), all the groups were significantly different from each other at $p < .05$. Regarding Phonological similarity (similar and dissimilar items), the YC group was significantly different from the GDS 2, GDS 3, and GDS 4 groups at $p < .05$. The GDS 2 group was significantly different from the YC, GDS 3, and GDS 4 groups at $p < .05$. Grouping scores were obtained by providing one point for each response that followed a similar classification, (words or letters, phonologically similar or dissimilar); a point was subtracted for each change that occurred in response classification.

Figure 7


20
15
10
5
0
Mean Grouping Score
Category
Phonological Similarity
YC
GDS 2
GDS 3
GDS 4
GROUP

APPENDIX

Mean Number Correct In Immediate Recall as a Function of Group, Modality, Phonological Similarity, Category, and Position

	Serial Position						
	1	2	3	4	5	6	*M*
YC							
Auditory							
Similar							
Words	6.56	5.81	4.69	5.75	5.25	6.19	5.71
Letters	7.00	6.31	5.94	6.06	6.19	7.06	6.43
Dissimilar							
Words	6.81	6.19	6.38	6.13	6.25	6.94	6.45
Letters	7.44	6.94	7.06	7.31	7.75	8.00	7.42
Visual							
Similar							
Words	7.06	6.56	6.44	6.56	6.38	6.31	6.55
Letters	7.50	6.81	6.06	6.44	5.56	5.63	6.33
Dissimilar							
Words	7.31	6.81	6.38	6.31	5.88	6.31	6.50
Letters	7.94	7.56	7.63	7.50	7.50	7.69	7.64

(table continues)

Mean Number Correct In Immediate Recall as a Function of Group, Modality, Phonological Similarity, Category, and Position (continued)

	Serial Position						
	1	2	3	4	5	6	*M*
GDS 2							
Auditory							
Similar							
Words	5.44	3.81	2.75	3.31	3.44	4.00	3.79
Letters	5.25	4.38	3.69	4.31	3.13	4.56	4.22
Dissimilar							
Words	6.44	5.06	4.38	4.31	5.13	6.06	5.23
Letters	7.13	6.06	5.63	5.81	6.19	6.81	6.27
Visual							
Similar							
Words	5.69	4.81	3.88	3.56	3.38	3.00	4.05
Letters	5.81	4.50	3.69	2.69	2.94	3.56	3.86
Dissimilar							
Words	6.06	5.00	4.31	4.19	3.56	4.25	4.56
Letters	6.94	6.25	6.19	5.38	4.81	5.50	5.84

(table continues)

Mean Number Correct In Immediate Recall as a Function of Group, Modality, Phonological Similarity, Category, and Position (continued)

	Serial Position						
	1	2	3	4	5	6	*M*
GDS 3							
Auditory							
Similar							
Words	4.50	3.06	2.19	2.13	1.94	2.69	2.75
Letters	4.25	2.94	2.19	2.56	2.13	3.44	2.92
Dissimilar							
Words	5.56	4.06	3.06	3.38	3.00	3.88	3.82
Letters	6.56	5.00	4.75	4.25	5.19	5.75	5.25
Visual							
Similar							
Words	5.19	3.38	3.13	2.75	2.19	1.81	3.07
Letters	4.69	4.31	3.31	2.63	1.75	2.69	3.23
Dissimilar							
Words	5.56	4.06	3.38	2.44	2.06	2.00	3.25
Letters	6.69	5.88	5.44	5.19	4.44	4.63	5.38

(table continues)

Mean Number Correct In Immediate Recall as a Function of Group, Modality, Phonological Similarity, Category, and Position (continued)

	Serial Position						
	1	2	3	4	5	6	*M*
GDS 4							
Auditory							
Similar							
Words	4.38	2.38	2.00	1.44	1.31	1.44	2.16
Letters	3.94	2.88	2.06	2.00	1.31	2.31	2.42
Dissimilar							
Words	4.81	2.81	2.69	2.81	2.88	3.06	3.18
Letters	6.31	4.50	4.69	4.88	4.63	5.19	5.03
Visual							
Similar							
Words	4.63	2.88	2.25	1.75	1.13	0.69	2.22
Letters	5.13	3.94	2.19	1.94	1.38	1.69	2.71
Dissimilar							
Words	4.88	3.62	2.94	1.75	2.06	1.31	2.76
Letters	6.69	4.94	4.44	4.25	3.69	3.88	4.65

Note. Maximum score at each serial position is 8.00.

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