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Visual Selective Attention in Alzheimer's Disease: Effects of Physical Similarity, Density, and Target-to-Distractor Ratio in a Cancellation Task

by

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A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

2002

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

Jan 23, 2002
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Abstract

VISUAL SELECTIVE ATTENTION IN ALZHEIMER'S DISEASE: EFFECTS OF PHYSICAL SIMILARITY, DENSITY, AND TARGET-TO-DISTRACTOR RATIO IN A CANCELLATION TASK

by

Lynn Anne Schaefer

Adviser: Professor Nancy S. Foldi

Patients with Alzheimer's disease (AD) have deficits in visual selective attention. Two experiments examined the effects of systematically varying the physical characteristics of a cancellation task on qualitative (omission and commission errors) and quantitative (completion time) measures of performance. It was posited that higher physical demands represent increased perceptual load, and that the increased load would impair selective attentional skills in AD.

In Experiment 1, 15 AD subjects and 15 age-matched controls were administered 18 cancellation tests varying by 3 levels of physical similarity between targets and distractors (Similarity) and 3 levels of number of items per page (Density). AD subjects made more commission errors at the highest and middle levels of Similarity ($p<0.05$), and took longer than controls ($p=0.06$, trend) both as Similarity increased and at the highest Density level ($p<0.05$). Increased commission errors and completion time at higher levels, and not at the lowest level, show that increased task load affects AD subjects.

In Experiment 2, 15 AD subjects and 15 age-matched controls were administered 15 cancellation tests varying by 3 levels of Density and 5 levels of the number of targets relative to the number of distractors (Target-to-Distractor Ratio). AD subjects made significantly more commission errors as Target-to-Distractor Ratio and Density interacted ($p<0.0001$), and took longer than controls as Target-to-Distractor Ratio increased ($p<0.01$). The AD subjects' greater completion time may in part reflect more time needed to cancel distractors, but may also reflect a less efficient search strategy as perceptual demands of Target-to-Distractor Ratio change. However, both groups canceled stimuli at the same rate (completion time/total cancellations).

The current findings suggest that selective attention skills in AD are intact at lower levels of perceptual load, where attentional capacity is not taxed. The selective attention deficits in AD were revealed only at high levels of perceptual load (e.g., at high levels of physical discrimination, and at the interaction between quantity and relevance of items). At these higher attentional loads, impoverished inhibitory mechanisms affected performance. These data suggest that commission errors are associated with compromised executive functioning, which contributes to the selective attention deficits in Alzheimer's disease.

Acknowledgements

The author wishes to express her deepest appreciation to her Chairperson, Dr. Nancy S. Foldi, for her expertise and mentorship. In particular, I wish to thank her for her guidance and her generous donations of time.

Sincere thanks go to Committee members Dr. Ray Johnson, Jr. and Dr. Daniel V. Caputo, for their timely critiques of the present work, as well as for their patience and encouragement. Dr. Johnson is also credited for serving as an earlier Chairperson, and Dr. Caputo for continuing to serve on the committee in spite of his retirement.

Thanks also go to Dr. Howard Ehrlichman and Dr. Karen Dahlman for serving as outside readers on this dissertation, and for their contributions.

I would like to recognize and give special thanks to Dr. Richard E.C. White for his statistical insights, computer expertise, graph making, and generous offers of help throughout the course of this work. Mr. John Zhu is acknowledged for developing the computer program that randomly distributed stimuli in the experimental test.

Thanks go to the physicians of the Geriatrics Division at Winthrop-University Hospital, Dr. Lucy Macina, Dr. Jeffrey Berger, and Dr. Maria Torroella Carney, for referring patients to the study. Thanks also go to Dr. Giselle Wolf-Klein and Dr. Alan Steinberg for referring patients.

My sincerest appreciation goes to all of the subjects who participated in this study, and their families.

I wish to thank my friend Lawrence Pick for his continued support and encouragement, as we went through the graduate school process together. Our gripe-sessions and commiserating helped me through.

On a personal note, my special thanks and most profound gratitude goes to my husband and best friend, Marc S. Bekerman, for his unending support, patience, understanding, and love throughout my years of graduate school, and for helping to make this possible.

This work is dedicated to our children, William and Elizabeth Bekerman, who bring balance to my life and inspire me every day to be a better person. I also dedicate this work to the memory of my grandmother, Helen E. Schaefer.

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INTRODUCTION

The purpose of the present study was to examine visual selective attention in Alzheimer's disease (AD). Experimental evidence has demonstrated that AD patients have difficulty with several components of attention (Cossa, Della Sala, and Spinnler, 1989; Perry and Hodges, 1999), especially visual selective attention (Foldi, Jutagir, Davidoff, & Gould, 1992; Parasuraman and Haxby, 1993). However, since it is not clear which component of selective attention is compromised in AD, this study investigated the effect of changes in physical characteristics of a visual selective task in AD patients.

The study of selective attention has a long history. One of the first published definitions of attention was by William James (1890), who wrote that attention was "the taking possession of the mind...of one out of what seems several simultaneously possible objects or trains of thought (ibid, p.416)." This idea of filtering simultaneous stimuli has been dealt with in many ways. Gestalt theory (Kohler, 1947) conceived of the figure-ground concept and ways to switch back and forth between them: Cherry (1953) investigated the notion of selectivity of simultaneously attended and 'unattended' acoustic information, and Broadbent's (1958) filter theory was derived from telecommunication models in which not all of the incoming information was passed along to the point of processing. While different in their approaches, these theories all assumed some type of mechanism to explain how information is singled out, or selected, from amidst other surrounding information.

Selective attention is viewed as one subtype of the domain of attention. Each subtype (Davies et al., 1984; Posner, 1980; Stuss et al., 1995) is believed to have its own underlying neurological system (Posner and Petersen, 1990), and although different researchers assign different names to these subtypes, they include alerting, vigilance, focused or sustained attention, and divided attention, as well as selective attention. Attention is not globally affected in AD (Parasuraman and Haxby, 1993). Rather, selective attention is thought to be highly vulnerable in AD due to the underlying structural and neurochemical changes of the disease. Some aspects of the selective attentional process may be spared, while others are disrupted. It was hypothesized that visual search per se is manageable by AD patients, but the threshold at which their selective search performance deteriorates is altered by the disease. The purpose of the present investigation was to explore how physical characteristics of stimuli in the visual field may make the selection task more demanding for AD patients as compared with non-AD individuals.

The methodology of this investigation involved the use of a selective cancellation test (paper and pencil tests in which targets have to be selected and cancelled while ignoring distractors), and the systematic manipulation of the visual display. In particular, the study investigated three physical variables of this display: physical similarity (similarity between stimuli), density (set size), and target-to-distractor ratio (the degree to which stimuli stand out from their surround). Using quantitative (completion time) and qualitative (omission and commission errors) measures, it was predicted that aspects of

physical similarity, density, and target-to-distractor ratio would more adversely affect AD patients than age-matched controls because selective search mechanisms that require multiple inhibitory and disengaging skills are especially vulnerable in AD patients. Specifically, we predicted that the interaction between speed and accuracy would demonstrate that AD patients have difficulty making visual discriminations in the context of a selective search when attentional demands are taxed.

The following review will highlight prominent psychological and neurobiological models of attention that pertain to selective attention. The psychological models will focus on the concept that attentional capacity is restricted; several theories have been proposed as to how this selective mechanism functions as attentional demands tax the capacity of the system. The review of current neurological models includes proposals of several discrete neural attentional networks thought to subserve different aspects of attention, with emphasis on mechanisms for selective processes. These reviews are followed by an analysis of past research into visual selective attention in AD.

Psychological Models of Attention

Attentional Capacity

The visual system, like all sensory systems, is confronted with large amounts of information that surpass what can be processed by peripheral and central neural components. This restriction on the amount of attention that can be utilized at any one time, and therefore on the amount of information that can be processed or the number of tasks that can be performed at one time, has been referred to as the concept of limited

capacity (Broadbent, 1958; Cherry, 1953; James, 1890; Kahneman, 1973). It appears that some type of mechanism, therefore, is invoked to limit the quantity of information.

Filter and Resource Models

One type of mechanism that has been proposed to limit information is the selection or filtering of information to be processed. The concept of a filter was one way to reduce the information to a more manageable amount for the system. Filter theories assumed that there is a structural bottleneck at some stage of processing, which can only handle one stimulus at a time. Some theorists placed this bottleneck, and therefore a filter, early in the information processing sequence (Broadbent, 1958; Treisman, 1964) before the stage of analysis, while others placed it later in the sequence (Deutsch and Deutsch, 1963; Norman, 1968). The filter concept opened theoretical distinctions between information that was selected or relevant, versus material that was unselected or irrelevant. While theories vary as to how this is purportedly done, this is the foundation of the concept of selective attention theory.

In contrast to the structural bottleneck metaphor of filter theories, capacity theories used an energy metaphor of "mental effort" or "resources". Capacity theories assumed that attentional processes require resources, and that these resources are limited. Kahneman (1973) argued that, "Instead of such bottlenecks, a capacity theory assumes that there is a general limit on man's capacity to perform mental work. It also assumes that this limited capacity can be allocated with considerable freedom among concurrent activities (ibid, p. 7-8)." Kahneman proposed that the allocation of capacity depended

both on the subject's arousal level, and on the activity's demand on capacity. When arousal is moderately high, more capacity is available than when arousal is low. Further, arousal can increase when task demands increase. Different tasks place varying demands on capacity. The amount of attentional effort that a task demands has been referred to as its perceptual "load" (Kahneman, 1973; Kahneman and Treisman, 1984; Lavie, 1995; Lavie and Tsal, 1994; Rabbitt, 1963); high-load conditions use more attentional capacity, whereas low-load conditions use less. Examples of high-load situations include highly similar targets and distractors (Duncan and Humphreys, 1989), increasing numbers of stimuli (Duncan, 1980; Navon, 1989), and 'conjunctive' stimuli, in which the target shares more than one feature with the distractors (Treisman and Gelade, 1980; Treisman and Sato, 1990). When task demands exceed capacity, performance deteriorates. Experimental investigations have sought to understand how the manipulation of load can serve to maximize or minimize demand on attentional capacity. These investigations will be reviewed later.

While Kahneman's model involved a single, undifferentiated pool of resources, the multiple-resource model proposed that different tasks could demand separate resources (Navon and Gopher, 1979; Wickens, 1984). In Wickens' model, resources are divided along input modality – visual or auditory, processing code – spatial or verbal, and response modality – manual or vocal. These were roughly differentiated both within and between cerebral hemispheres, so that visual-spatial tasks were processed to a greater degree by the right hemisphere and auditory-verbal tasks by the left hemisphere. Thus,

interference between tasks occurred only when the tasks demanded similar resources, and competed for neural processing mechanisms.

All of these cases suggested that either a mechanism to decrease or 'select' information or to decrease task demands on available resources was a way to compensate for the limits in the quantity of information that capacity could process.

Models of Attentional Processing

Another way to limit informational input is to distinguish the information being processed. The distinction can be based on the quality of the information processing, as for example classifying processing as automatic or effortful (Hasher and Zacks, 1979) or parallel or serial (Townsend, 1971), or processing can be distinguished based on the timing of the analysis of the material, such as preattentive or attentive (Neisser, 1967). What these models shared was the notion of a dichotomous nature of the selection. Material was either 'easy' or 'hard', less demanding of attention or more demanding of attention. While there existed two distinct modes of processing, these models were not necessarily viewed as mutually exclusive, however, in that one type of processing could evolve into the other under special circumstances, such as in conditions of repeated rehearsal (Shiffrin and Schneider, 1977). These dichotomous models will be later contrasted with some of the more recent approaches that suggest that information processing can best be conceived of as a continuum, or that the situation dictates which selection mechanism is more advantageous, while still accepting some of the assumptions first documented in these earlier models.

Dichotomous Models of Attentional Processing

One way to distinguish the information being processed was with the parallel versus serial dichotomy, which was adopted from computer analogies. Parallel processing assumed that all information is processed simultaneously whereas serial processing assumed that information is dealt with sequentially (Neisser, 1967; Townsend, 1971). Parallel processing is thought to occur quickly, superficially, and without taxing capacity limits (inflexible). In contrast, serial processing is thought to be slow, detailed, and affected by overall quantity (flexible). However, as will be discussed, this serial-parallel dichotomy has its opponents (Duncan and Humphreys, 1989; Egeth, Virzi and Garbart, 1984; Wolfe, 1994,1996a).

The visual search paradigm (search for a single object among distractors) was one approach to assessing which of the two ways information was analyzed; some information was easier to process and thus was processed first or more quickly, while other information put more demand on the available capacity, and might be processed more slowly. In a parallel search, increasing the amount of information does not change the completion time of the target detection, since features are processed simultaneously. In contrast, in a serial search, where each item is processed individually, increasing the set size would also increase the search time of the target (Sternberg, 1966). Thus, in plots of reaction time as a function of set size, a shallow slope (< +1.0) indicates parallel processing, whereas slopes approaching +1.0 indicate slower, serial processing.

An additional way of looking at the dichotomy concerns preattentive versus attentive processing. Neisser (1967) stated that preattentive processes, which act in parallel (and thus, do not tax capacity), are the "preliminary operations" that "produce the objects which later mechanisms ...interpret (ibid, p89)." According to Neisser, the attentive processes depend on the information supplied by the preattentive processes in order to perform further perceptual analyses. Thus, the relation between preattentive and attentive mechanisms was linear and sequential. Many later two-process theories shared this preattentive-attentive distinction, or the notion that one type of information supplied the next level. Schneider and Shiffrin's model (1977) focused on the preattentive-attentive dichotomy as a way to analyze attentional mechanisms. These authors drew on the concepts used in memory research and applied them to mechanisms of attention, proposing the dichotomy of automatic and controlled attentional processes. Automatic processing was preattentive, came from long-term memory, and operated outside the subject's control. It did not exhaust capacity. Controlled processing was seen as attentive, often serial, exhaustive of capacity, and operating under the subject's control. The authors proposed that qualitative changes in performance occurred as subjects consistently performed a given search task (Schneider, Dumais, and Shiffrin, 1984; Shiffrin and Schneider, 1977). Specifically, unpracticed search tasks involved more controlled processing, whereas practiced tasks became automatic. Thus, with practice, the mechanism for processing complex tasks can change to require little attentional capacity. This theory, along with that of Kahneman (1973), indicated that the attentional

processing mechanism could change as a function of the task demands and subject's experience. In short, the way a subject addressed the information could change the way the attentional demands were allocated. While these authors recognized that controlled processes could become automatic, the reverse was not also true.

The model proposed by Hasher and Zacks (1979) also drew on concepts used in memory to address attention. 'Effortful' tasks demanded more attention, while 'automatic' tasks required fewer attentional constraints. Capacity limits interacted with type of processing, such that effort-demanding tasks used up more of the capacity.

Another way to posit a two-part division of attention is that of resource-limited and data-limited performance (Norman and Bobrow, 1975). Norman and Bobrow proposed that when performance was dependent on the quality of the stimulus or input, it was referred to as data-limited performance, and when performance was dependent on an organism's efforts or ability, it was referred to as resource-limited performance. In actuality, however, they noted that most tasks actually required a combination of both resource-limited and data-limited performance, recognizing the limitations of a strict dichotomous view of attentional resources.

Treisman has been instrumental in proposing a theory of attentional allocation. First interested in the processing of physical features, Treisman (1964) recognized that attentional performance was dictated by manipulation of physical characteristics, much in the same way that Rabbitt (Rabbitt, 1962, 1964, 1967) had done originally in audition. The feature-integration theory (Treisman and Gelade, 1980) again emphasized the

dichotomous nature of attentional mechanisms. In the first stage, features were analyzed preattentively, using parallel processing. The second stage was an attentive scan using serial processing. The makeup of the stimulus determined which stage was employed. For example, when stimuli differed dramatically by one feature, such as color, the target appeared to "pop out" (Neisser, 1963; Treisman, 1986) from the surround (e.g., search for a red circle among blue circles). This type of stimulus required the preattentive, parallel stage of processing. If subjects could preattentively detect a target by analyzing only one feature of the stimuli (which she termed feature searches), this placed less demand on the attentional system. In another dichotomy, Treisman and Gelade (1980) contrasted a disjunctive search (e.g., search for *either* a red *or* a vertical; same as a feature search) with a conjunctive search (e.g., a search for red *and* a circle). Conjunctive stimuli were stimuli in which the target shared *more than one* feature or attribute with the distractors, making the detection task more difficult (e.g., search for a red circle among blue circles and red squares). Treisman's proposal was that a conjunctive search forced subjects to use serial detection to identify the target, because features had to be analyzed individually and then conjoined, or combined back into objects. Using the concept of slope, they demonstrated serial search by showing that completion time increased with increasing set size. This positive slope was found both in conditions involving conjunctive stimuli and when stimuli were very physically similar to each other.

All of the dichotomous models described previously share the concept that attentional processing mechanisms are invoked in an 'either-or' fashion: either the

material is handled in a preattentive or in an attentive way; search is either serial or parallel, disjunctive or conjunctive. But these either-or explanations of how attentional capacity is allocated have limitations. It was increasingly apparent that the strict dichotomous explanations of limiting incoming visual information were not sufficient. It was felt that models had to incorporate a more integrative approach such that attentional mechanisms could vary depending on factors such as the situation, the demands being placed on the subjects, and the subject's past knowledge and experience. The alternative models had to incorporate a more dynamic mechanism that could allow for changing attentional demands. The following section will introduce these newer concepts in allocation of attentional capacity. Unlike the strict dichotomies, these models accommodate several processes, or adjust to the demands of the situation in explaining how the attentional resource is used.

Integrative and Dynamic Models of Attentional Processing

Guided search.

One argument against the strict parallel-serial dichotomy is its inefficiency, in that a search was only parallel or only serial. The question arises as to whether a conjunctive search could be more efficient if a subject first used parallel processing to reject items that did not contain a required feature of the target, and then used serial processing to discriminate the remaining items. For example, when searching for a red circle amidst blue circles and red squares, subjects could reject blue items (i.e. parallel search) and then restrict their search to only red circles and squares (i.e. serial search). This mechanism

was proposed by several researchers (Duncan and Humphreys, 1989; Egeth, Virzi and Garbart, 1984; Wolfe, 1994; Wolfe, Cave and Franzel, 1989; Wolfe and Gancarz, 1996), who suggested that parallel processes guided subsequent serial processing. This approach has been referred to as "guided search". Treisman ultimately revised the earlier feature-integration theory (Treisman, 1988; Treisman, 1993; Treisman et al., 1992; Treisman & Sato, 1990) to incorporate this notion that serial detection could be directed by parallel, preattentive information.

Wolfe (1994,1996a, 1996b; Wolfe and Gancarz, 1996) has elaborated the guided search by proposing a continuum from entirely parallel (e.g., shallow slope for reaction time x set size) to entirely serial (i.e. steep slope varying with increased set size) search. A guided search incorporated preattentive, parallel features (such as color saturation, orientation or density of the stimuli), while simultaneously allowing an item-by-item search to proceed, guiding the individual in a more directive manner, as it were. The two components of the search guided the individual's attention depending on the salience or surface characteristics of the field. There was nothing intrinsically 'parallel' or 'serial' about color saturation or density features, but the salience of that feature in the context of the array, at any given time, could direct either or both search strategies to be operative. Importantly, however, guided search, unlike simple parallel or serial search, became a more efficient search strategy.

Top-down and bottom-up processing.

Another limitation of the dichotomous models of processing was that they appeared too simplistic in that they failed to take into account the interaction between the extrinsic, environmental components and the intrinsic, cognitive strategies of the individual. The intrinsic and extrinsic functions, discussed in early writings of James (1890) and Titchener (1910), and later Broadbent (1958), were adopted in computer algorithms and ultimately developed into the concepts of top-down and bottom-up processing. The interaction of top-down and bottom-up processing has become one of the leading theories and is seen as the essence of an efficient use of attentional resources.

Wolfe (1994,1996a) has developed a theory integrating top-down and bottom-up processes. In his theory, the initial, parallel, processing of stimuli results in the creation of individual representations for a limited set of basic features (size, orientation, color), which he calls feature maps. The purpose of these feature maps is to identify locations requiring further attention; the more activation in a location, the more probable it is that it will capture attention. Activation, according to Wolfe's model, is made up of both bottom-up activation (determined by how different an item is from its neighbor (its salience)) and top-down activation (determined by the user, or instructions to look for a particular feature). The weighted sum of these activations is used to create an activation map, which then guides search by directing attention to the location with the highest activation. Activation maps are dynamic, and change as a function of the intrinsic or extrinsic factors needed for a given search task. When there is a large difference between

the target and the surrounding stimuli, strong bottom-up activation would be invoked. The target is easily detected in an efficient manner and top-down activation would contribute minimally. If, however, the subjects were given instructions (such as to restrict their search to one type of stimuli; e.g., to attend to all red items), the top-down influences could override stimulus salience in order to make the search more efficient (Bacon and Egeth, 1997). Or, once there is minimal physical difference between the stimuli and the surround, the bottom-up mechanism is less efficient, and therefore more top-down processing, derived from the subject (as opposed to being given instructions), can assist in an effective search (Zohary and Hochstein, 1989).

Top-down processing comes from a subject's cognitive involvement and can be based on prior knowledge or expectations about the type or location of the target. In a sense, top-down processing is the way of directing the search to 'what' the target is, or 'where' the target is (Reynolds and Desimone, 1999; Reynolds, Pasternak and Desimone, 2000).

Duncan and colleagues also proposed an interactive model of top-down and bottom-up processing. In their integrative, competitive hypothesis, they suggest that top-down working memory processes bias, or prime, which object is attended to. When there is competition among multiple objects for attention, the competition can be resolved by the individual's overriding cognitive directives (Desimone and Duncan, 1995; Duncan, 1999; Duncan, Humphreys and Ward, 1997). One type of overriding directive can be the label of the target with a 'vocabulary' item (Wolfe, 1996a). This guides the search to 'red

items' or 'steep items.' The use of vocabulary succeeds best when the category is unique, but is less effective when the category chosen does not uniquely differentiate the stimuli (e.g. finding the steepest line among an array of steep lines; Wolfe 1996a).

Conjunctive searches can be seen as another example where top-down and bottom-up processes interact (Cave and Wolf, 1990). In a conjunctive search, targets and distractors share at least one feature (a red circle amidst blue circles and red squares). If only top-down mechanisms were operative, all 'red' or all 'circles' could be searched, using the color or shape semantic label. In this instance, all 'red' items would receive strong top-down activation and all 'circles' would receive top-down activation because of shape. In the case of triple conjunctions (e.g., big red O amidst small red X's, small green O's, and big green X's), search is even easier than in a standard conjunction because there are three sources of top-down information with which to limit the search, as opposed to just two (Wolfe, Cave and Franzel, 1989). But neither top-down nor bottom-up mechanisms alone will satisfy a conjunctive search. Therefore, the interaction between the two has to be operative. Top-down processing helps to narrow the search, but bottom-up activation is necessary for completion of the search.

Another interaction between top-down and bottom-up processing was proposed by Duncan and Humphreys (1989) in their similarity theory. They proposed that the physical difference between targets and distractors determined the contribution of top-down or bottom-up processing to the search. Their experiment compared stimuli that were more different (i.e., a search for 'L' among 'T's) to stimuli that were more similar

(i.e., a search for a 'tilted T' among 'straight Ts'). When the physical similarity between the target and the distractors was large, the target activation increased, and the search for the target was efficient with more bottom-up processing. However, as the physical similarity between the target and distractors increased, the target activation decreased, and the search became harder with more top-down processing needed since bottom-up processing alone was insufficient. In the current experiment, this dimension of similarity will be investigated. Since it is proposed that AD subjects are less able to draw on top-down, semantically-based mechanisms (Monsch et al., 1992), their search strategy will therefore rely on more lower-level, less efficient, bottom-up processing.

The top-down – bottom-up mechanisms of search continue to be a leading theoretical explanation of the visual search paradigm. Integrated with the guided search hypothesis, it offers a dynamic, flexible mechanism of attentional allocation that can be dependent at any given time on the subject's instructions, or as a function of the novelty or salience of the environmental surround. Lastly, let us consider a cognitive role of attention related to that of top-down processing, which is the attentional control over actions, thoughts, and executive processes. These models have close connections with memory as well as attention.

Models of Attentional Control

Shallice (Norman and Shallice, 1986; Shallice and Burgess, 1993) proposed that two mechanisms controlled actions and thought-processes. One mechanism chose between programs for well-learned actions and thoughts, or schemas, only under routine

situations. This was known as contention-scheduling. Contention-scheduling was an automatic process and chose schemas from long-term memory based on external, salient factors. When confronted with a novel situation, however, the Supervisory Attentional System (SAS) provided voluntary, top-down modulation of contention-scheduling in order to choose an appropriate schema from working memory. The role of the SAS was that of a central control mechanism which coordinated activities by resolving interference between action schemas. For example, if an action were environmentally triggered but conflicted with the individual's goals or expectations, the SAS would inhibit activation of the inappropriate schema and provide additional activation to a more appropriate schema. Thus, the SAS's attentional control over action, through inhibition, could override salient environmental stimuli and habitual responses. According to this model, the SAS corresponds neuropsychologically to executive functioning, and is subserved by the prefrontal cortex, as supported by deficits exhibited by patients with lesions to this area (Shallice and Burgess, 1993). These deficits would manifest themselves as distractibility, perseveration of ongoing or inappropriate behavior (based on contention-scheduling), and inability to initiate or modify behavior to adapt to a novel situation (due to SAS damage). Since the cancellation task in the present study represents a novel task, it was anticipated that AD subjects would have difficulty activating new schemas, and inhibiting inappropriate schemas, in order to perform it. This is because, as already mentioned, AD subjects are less able to draw on top-down mechanisms (Monsch et al., 1992), and

because, as will be reviewed, AD subjects have damage to frontal regions of the brain (Braak and Braak, 1991, 1995; Montaldi et al., 1990).

Analogous to the idea of the SAS is the concept of a Central Executive, which is attentional in nature, resides in working memory, and is involved in supervisory or executive control over attentional allocation (Baddeley, 1986). In Baddeley's model, working memory is composed of three components: a visuo-spatial sketchpad, which holds and manipulates visuospatial information; a phonological loop, which deals with speech-based information; and the Central Executive, which coordinates and allocates attentional resources to the other two components, and links them to long-term memory. The Central Executive, like the SAS, also has a limited capacity. Baddeley (Baddeley et al., 1986) proposed that the attentional demands on the Central Executive of performing two tasks simultaneously could account for attentional deficits in AD. Deficits of divided attention in AD have, in fact, been documented elsewhere (Baddeley, Baddeley, Bucks and Wilcock, 2001; Nestor, Parasuraman, Haxby and Grady, 2001; Perry and Hodges, 1999). Like the SAS, the Central Executive also appears to be subserved by frontal components (Baddeley, 1993). However, whereas the SAS appears to be equated with executive functioning, the Central Executive has been associated with the attentional control of executive functions.

Thus, these models of attention both point to a dominant, "executive" or "supervisory", role of attention in the control of other cognitive processes such as thought

and action. Furthermore, these models support the interaction of attention with executive functioning, within the framework of working memory.

Neurobiological Models of Attention

A number of theories divide attention into subcomponents, each of which is thought to be subserved by different brain areas. Neurobiologic models that have been proposed include those by Posner (Posner and Petersen, 1990), Mesulam (Mesulam, 1981, 1998, 2000), and Stuss (Stuss and Benson, 1984; Stuss, Floden, Alexander, Levine and Katz, 2001; Stuss et al., 2000; Stuss, Shallice, Alexander and Picton, 1995; Stuss et al., 1999), and an attention model based on the dual visual processing system (Kastner and Ungerleider, 2000, 2001; Mishkin, Ungerleider and Macko, 1983; Reynolds and Desimone, 1999; Reynolds, Pasternak and Desimone, 2000; Ungerleider and Mishkin, 1982). Each will be discussed in turn, stressing the relevance of the theory to the proposed visual selective attention task.

Posner Model

Posner's neurobiological approach (Posner, 1980) divides attention, both in terms of cognitive function and neurological structure, into two major areas: the posterior–orienting and the anterior–detection networks (Posner and Petersen, 1990). While each subsystem can act independently, the two networks also interconnect, allowing for multiple aspects of a task, such as both the orienting and detection of a stimulus. A third area, the alerting network (subserved by the ascending reticular activating system

(ARAS)), can influence both anterior and posterior networks, operating at high- or low-levels of arousal.

According to Posner's model, the orienting subsystem involves slower overt shifts of attention (involving volitional eye movements), and faster covert shifts of attention (operating in the absence of eye movements). The model articulates that shifting attention from one stimulus to another involves processes of engagement and disengagement. The orienting subsystem is subserved by the posterior parietal cortex (disengagement), the superior colliculus (shifting attention), and the lateral pulvinar (extracting information from the target location and filtering distractors), which together make up the 'posterior' attentional network (Posner and Petersen, 1990). It should be noted that this 'posterior' system also involves projections to lateral and medial frontal areas (Posner, 1995), highlighting that this system also projects to and incorporates components of the frontal system. The orienting subsystem has been shown to be compromised in patients with focal parietal lesions (Posner, Walker, Friderich and Rafal, 1984, 1987). These subjects show increased completion time when their attention is directed to an invalid target location, stressing their inability to disengage from the incorrect location and redirect to the correct target location. Further investigation has shown that this orienting system is also compromised in AD, where the neuropathology typically involves both parietal as well as lateral frontal systems (Braak and Braak, 1991, 1995). Specific tasks that require disengagement are difficult for AD patients on the invalid cue (cued to an invalid target location) covert-orienting paradigm (Maruff,

Malone and Currie, 1995; Oken, Kishiyama, Kaye and Howieson, 1994; Parasuraman, Greenwood, Haxby and Grady, 1992).

In addition to the covert paradigm, cancellation tasks also contain elements of engagement and disengagement. Search for multiple targets among distractors can thus be conceptualized as tapping processes similar to the cued covert-orienting paradigm. Inability to disengage from one target to another, or inability to disengage from a distractor, would support that the underlying neural process could be a deficit in the posterior system, involving at least posterior parietal regions.

In Posner's model, the 'anterior' network serves as the detection subsystem (or executive attention subsystem), and involves detecting stimuli either from sensory events or from memory. The neurobiological substrate of this anterior network includes the anterior cingulate gyrus and the midline frontal region (Posner and Petersen, 1990). The areas that are part of the anterior system are also areas affected in AD. For example, studies measuring regional cerebral blood flow (rCBF; Montaldi et al., 1990) or metabolic rates for glucose (Grady, et al., 1988; Grady et al., 1990) using positron emission tomography (PET), have found hypoperfusion and hypometabolism, respectively, in the frontal cortex, as well as in parietal and temporal regions. Further, it appears that this anterior network can modulate the functions of the posterior network, again demonstrating the interconnectedness between the two networks (Posner and Driver, 1992).

This anterior system is thought to be more involved in initiation and search, and is highly vulnerable to interference. For example, auditory, linguistic stimuli can interfere with search (Posner, 1989), making it slower. This type of vulnerability is akin to the effects seen in divided attention tasks, where the simultaneity of stimuli places competing demands on the allocation of attention. Resolution of the competition is directed by the executive system (Stuss, et al., 1995), and failure of this system may be expressed as deficits in the inhibitory mechanism. Thus, if the anterior attentional network is defective, as is implied by cortical frontal damage in AD, then tasks that evoke competitive decision-making are apt to be compromised. In paradigms where the opportunity exists not only to detect the target, but also to err in that selection by choosing a non-target, deficits in the anterior network would lead to errors of inhibition. This was exemplified in the studies of Simone and Baylis (1997) and Foster, Behrmann, and Stuss (1999), which found decreased inhibition and greater distractibility among AD patients on visual search tasks. Thus, inhibitory errors, such as commissions, appear to be indicative of impaired anterior, executive network disruptions.

In summary, Posner's model offers ways to explain many of the errors of visual selective tasks. While the alerting network is less involved in the dysfunctions seen in AD (Nebes and Brady, 1993), the posterior network particularly underlies disengagement problems, given the extensive cortical parietal involvement in AD, while damage to the anterior network is likely to impair the inhibitory mechanism needed to search for the correct target.

Mesulam Model

Mesulam's model of selective attention (Mesulam, 1981; Mesulam, 1998; Mesulam, 2000; Morecraft, Geula, and Mesulam, 1993) offers a more neurological basis of understanding search, detection and selection. In his model of selective attention, drawn from studies in primates as well as in humans with neglect, Mesulam proposed an attentional network made up of four cerebral regions, each with a unique function. Damage to any one component presents as a different profile, implying the dissociative nature of the attentional network. The four component regions include: a) the posterior parietal component, which provides an internal sensory representation of space; b) the frontal component, including the frontal eye fields, premotor and prefrontal cortices, which coordinates the motor programs for exploration, scanning, and fixating; c) the limbic component, composed of the cingulate gyrus, which regulates the spatial distribution of motivation; d) and the reticular component (composed of the ARAS), which provides arousal and vigilance (Mesulam, 1981; Mesulam, 1998; Mesulam, 2000; Morecraft, Geula, and Mesulam, 1993). Mesulam emphasizes that while the four components are separate and distinct, they are interconnected and form an integrated network for selective attention.

This model is similar to Posner's in that it also looks at attention neurobiologically, with different brain areas underlying different attentional processes. The value of Mesulam's model is that it proposes a neural basis for the interaction of these subcomponents. He supplies pathways, such as intercortical and intracortical

connections as well as articulation of which columnar layers are responsible for these connections. Using these pathways, Mesulam's model further proposes an "attentional matrix" (encompassing all attentional phenomena). This matrix is modulated both by neurons specific to a given modality (visual, language, faces, etc.) and by bottom-up and top-down influences (Mesulam, 2000). Bottom-up and top-down influences are discussed as a neuronal event, and not necessarily used as cognitive constructs. According to Mesulam, bottom-up modulation includes arousal from the reticular component of the network, while top-down modulation involves motivation and working memory from the parietal, frontal and limbic components.

To the extent that AD presents with cortical parietal, dorsolateral frontal and prefrontal, and limbic dysfunction, the attentional components subserved by these areas are at risk (Mesulam, 2000, p. 461). Bottom-up modulation of attention, subserved by an intact ARAS, remains relatively unaffected in AD and arousal is not impaired (LaBar et al., 2000; Nebes and Brady, 1993). In contrast, brain areas subserving top-down influences are the most affected. These areas implicate the cortical areas of the attentional matrix, resulting in impairments of exploration and scanning (frontal), the representation of personal and extrapersonal space (parietal), and motivation and expectancy (cingulate). If the searching of an array results in deficits in particular quadrants of the visual field, the prediction would be that the parietal subcomponent (representation of personal space) would be involved. Ishiai et al. (2000) and Mendez, Cherrier, and Cymerman, (1997) have both documented asymmetric bias toward the right

visual field, suggesting that neglect can occur in AD. These two studies implicate a bias in the attentional search. It would therefore be important in a task that requires an exploration of an array to test whether AD patients demonstrate an attentional bias.

Competition Model of Attention (Ungerleider, Desimone, Reynolds and colleagues)

Another model of selective visual attention has been proposed by Ungerleider, Desimone, Reynolds and colleagues (Desimone and Duncan, 1995; Kastner and Ungerleider, 2000, 2001; Reynolds and Desimone, 1999). These investigators advance a model of attention whereby competition occurs in the receptive field at the level of the neuron. They suggest how the situation is resolved when two objects are presented to a receptive field. When this occurs, there is mutual competition with one object suppressing the other. These neurons exist within both visual cortical pathways, the ventral and dorsal streams (Ungerleider and Mishkin, 1982), and can be used to select a location or an object.

What is interesting about this competition theory is the way attention can be used to manage competing stimuli (Reynolds and Desimone, 1999). In situations where two concurrent stimuli are competing, focused or directed attention can "counteract the suppressive influences of nearby stimuli, thereby enhancing information processing at the attended location" (Kastner and Ungerleider, 2000, p. 323). Competition can be biased by either bottom-up influences (such as salience or novelty), or top-down influences (such as working memory or task requirements) (Desimone and Duncan, 1995). While bottom-up biasing signals originate in visual cortex from stimulus-driven properties, top-

down signals originate in parietal and frontal cortex. In one study (Reynolds, Pasternak, and Desimone, 2000), monkeys were presented with two stimuli, each with a different orientation, and trained through prior cueing to direct their attention to a particular location (top-down biasing of attention). The monkeys' initial responses showed that the cell already had baseline activity to a particular orientation. Whenever the target appeared in a cued location, the monkeys attended and the cell activity was enhanced. In contrast, when the same preferred orientation occurred in the nonattended location, firing rates were lower. This then indicated that directed attention enhanced baseline neuronal activity, while inattention lowered firing rates.

Kastner and Ungerleider (2000) also demonstrated how attention could be used to enhance one of two competing stimuli. They investigated responses in a single receptive field in V4 in monkeys. Using two different stimuli (yellow and red bars), they showed that neuronal firing could respond to either stimulus individually, but when both stimuli were simultaneously presented, firing rates declined. That is, being in competition, they interacted with each other "in a mutually suppressive way" (ibid, p. 320). Again, directing preferential attention to one color (as a result of training) could resolve the competition, and determine which item was to be selected and which was to be ignored. The attended stimulus was enhanced, the suppression created by the presence of the distractor was reduced, and the salience of the attended stimulus corresponded to greater neuronal sensitivity.

The findings of Reynolds and Desimone (1999) and Kastner and Ungerleider (2000) thus support that top-down influences such as directed spatial attention or focused attention on a object are processes that can be used to enhance a stimulus. The attention instigates a physiological change that enhances the neuronal response of the attended stimulus.

This dual competition between stimuli is further supported by functional magnetic resonance imaging (fMRI) studies in humans (Kastner, DeWeerd, Desimone and Ungerleider, 1998; Kastner, DeWeerd, Maisog, Desimone and Ungerleider, 1997), that measured changes in blood flow in areas corresponding to V4. When stimuli were presented in close proximity to each other (as opposed to far apart), such that they subtended an area of a single receptive field, changes in blood flow were greater. A change in hemodynamic activity when two stimuli are close suggests that there is a human analog for suppression when two stimuli compete.

The results of these experiments may help explain the selective attentional deficits in AD. The ability to suppress information and direct attention to salient stimuli requires some kind of top-down instructions. These may be mediated by parietal or frontal cortices. In a selective search task, where targets are presented in a field of distractors, there has to be a mechanism to attend to the salient items. This dual competition model predicts that more dense presentations of targets and distractors will generate more situations of simultaneous information, and hence more competition. In AD, neuropathologic changes could be detrimental to the enhancement of the attended stimuli.

Alternatively, the effects of AD could interfere with mediation of the top-down instructions. Thus, in AD, where both temporal-parietal and frontal regions are affected (Braak and Braak, 1991, 1995), the decision-making tasks of attending to and canceling a target in a dense field will be vulnerable.

Frontal System Model of Attention (Stuss)

A model of attention that emphasizes the role of the frontal system was developed by Stuss and colleagues (Stuss and Benson, 1986; Stuss et al., 1995). This model divides attention into several tasks (i.e., sustaining, concentrating, sharing, suppressing, etc.), each involving elements of frontal system functioning. For example, according to this model, the task of concentrating attention involves the component processes of inhibition and activation, and appears to have an anatomical basis in the anterior cingulate. The task of suppressing attention, which involves inhibition, may be subserved by the dorsolateral frontal region. This attentional model, therefore, helps to clarify and localize the roles of the frontal system in attention.

Anterior mechanisms are also included in the other models, although those models do not emphasize the frontal component to the same degree. Posner's anterior system is made up of the anterior cingulate gyrus and midline frontal region, and is involved in detection, initiation and search. Mesulam's frontal component, including the frontal eye fields, premotor and prefrontal cortices, coordinates the motor programs for exploration, scanning, and fixating. The model proposed by Stuss et al. (1995) centers around the higher-order executive mechanisms, with inhibition and planning being the

predominant vehicles to direct attention. His model emphasizes the roles of specific cortical areas, such as the dorsolateral frontal, and superior and inferior medial frontal cortices. This model incorporates stimulus detection (Posner model) and motor programs (Mesulam model), but also includes higher-order executive functions such as inhibition.

In a study linking specific inhibitory tasks with frontal lesions in order to localize these functions, Stuss et al. (1999) tested frontal patients and controls on a primed spatial-selection task of visual selective attention. They found that patients with right frontal (including dorsolateral, striatal, and medial areas) and bifrontal damage showed increased interference on this task, as measured by increased completion time when presented with both a target and distractor simultaneously, as opposed to the target alone. Patients with left frontal damage showed a loss of inhibition of return (IOR). IOR is a delayed response to select a target displayed in a location previously occupied by a distractor, as a result of continued suppression of that location. In this study, left frontal patients actually showed faster completion times when the target appeared in a previously suppressed location. Right frontal patients displayed a reversal of inhibition when a previously presented target changed location and was later presented where the distractor had been previously (negative priming). Patients with left and bifrontal damage only showed this loss of negative priming in the most complex tasks. Thus, this study suggests that there may be an asymmetry in these frontal tasks, with each hemisphere underlying a different kind of inhibition.

In addition to the hemispheric asymmetry, Stuss aims to show that different frontal regions are responsible for specific executive functions. A series of studies by Stuss and his colleagues examined performance on neuropsychological tests sensitive to frontal lobe functioning in patients with localized frontal lesions. On the Wisconsin Card Sorting Test (WCST), patients with right and left dorsolateral damage showed difficulties with set loss, while patients with superior medial damage demonstrated perseveration errors (Stuss et al., 2000). In another study using the Stroop test (Stuss, Floden, et al., 2001), patients with left dorsolateral damage had increased errors and slowness for color naming, but not a selective interference deficit in the incongruent condition (stating the color word printed in a different color). Rather, this interference effect was seen in patients with bilateral superior medial frontal damage. The authors thus attributed the role of the superior medial frontal to that of activation and control. On the Trailmaking Test-Part B (TMT-B), Stuss et al. (2001) found that patients with damage in dorsolateral frontal areas were the most impaired, making the most errors, while those with inferior medial damage were not significantly affected. Taken together, these studies implicate the dorsolateral frontal areas in the role of keeping set, and the medial frontal areas in preventing interference. The mechanisms learned from these studies, therefore, include a component of keeping set (i.e., searching for the same target), as well as inhibiting interference from the surround.

Other studies also demonstrate the role of the right dorsolateral frontal cortex in attentional tasks. For example, early AD patients given a divided attention task show

increased activation in fMRI in this area (Johannsen, Jakobsen, Bruhn, and Gjedde, 1999). Selective attention, as measured by auditory dichotic listening tasks, has been shown to be impaired in patients with right dorsolateral frontal damage (Woods and Knight, 1986).

Studies of healthy elderly have demonstrated increased activation, as measured with fMRI, of prefrontal areas during divided attention tasks (Johannsen et al., 1997; D'Esposito, et al., 1995) and of medial and dorsolateral frontal areas during task switching (DiGirolamo et al., 2001). Even in healthy aging, studies have indicated a loss of neurons in the frontal cortex (Masliah, Mallory, Hansen, DeTeresa, and Terry, 1993) as well as decreases in frontal metabolism in older adults as compared to young adults (Alavi et al., 1986). These frontal vulnerabilities, while mild compared to AD, appear to underlie the trouble healthy elderly have with distraction (Plude and Hoyer, 1986; Madden, Connelly, and Pierce, 1994; Madden, Pierce, and Allen, 1996; Carlson, Hasher, Connelly, and Zacks, 1995) and decreased inhibitory processes (Godefroy, Lhullier, and Rousseaux, 1996; Kane, Hasher, Stoltzfus, Zacks, and Connelly, 1994; Kramer, Humphrey, Larish, Logan, and Strayer, 1994; McDowd and Oseas-Kreger, 1991) on visual selective attention tasks.

The frontal deficits in AD patients (Braak and Braak, 1991, 1995; Montaldi et al., 1990) appear to relate to attentional impairments greater than those that are seen in healthy aging. Specifically, AD patients have difficulty with keeping set (maintaining attention on a single task) (Paolo, Axelrod, Troster, Blackwell, and Koller, 1996), as well

as impairments in inhibitory processes and vulnerability to interference (Simone and Baylis, 1997; Foster, Behrmann, and Stuss, 1999). Thus, it can be expected that AD patients will have difficulty with the assessments employed in the present study. In particular, it is predicted that AD patients will have trouble staying in the set of searching for the same target, especially when there is more than one type of distractor in the surround (e.g., the array is very complex). Similarly, it is further expected that AD patients will have trouble inhibiting distractors and preventing interference, which would appear as increased errors of commission.

Each of the above neurobiologic theories of visual attention proposes a different but complementary mechanism. Posner's model divides attention into anterior and posterior networks, where the anterior network serves to detect stimuli and shift from one stimulus to another, and the posterior network underlies the mechanisms of orienting, engagement and disengagement. Mesulam's "attentional matrix", with four components (parietal, frontal, limbic and reticular), is subject to bottom-up and top-down influences. The competition model of attention proposed by Ungerleider, Desimone, Reynolds and colleagues, emphasizes how visual competition gets resolved, with elements of the competition acting at the level of the single neuron located in parietal regions of both dorsal and ventral streams, and elements of the competition derived from top-down directives from parietal as well as frontal cortical regions. Stuss' model brings to the field the concept that the frontal-subcortical system impacts many of the attentional functions, such as maintaining set and inhibiting interference, and that these are

subserved by discrete areas of the medial and dorsolateral cortices. All of these neurobiological models recognize that there is an interaction between anterior and posterior cortical regions, and that this interaction is critical for the gating and directing of attentional mechanisms. Certainly, the possibility that top-down instructions from frontal regions could dictate the individual functioning of parietal neurons suggests that the interaction and cortical-cortical connections between these two areas are vital in the attentional process. This intercortical communication is one area of vulnerability in AD. Parasuraman and Haxby (1993) discuss the disconnection (Geschwind, 1965) of the intercortical connections, and that those cortical layers that are susceptible to the neuropathology of the disease are the ones to support the intercortical transmission between these association areas. The effect of AD on these neurobiological substrates, and the influence of damage to systems needed to subserve selective visual attention, follows in the next section.

Selective Attention in Alzheimer's Disease

While AD is characterized primarily by amnestic, linguistic, executive, and visuo-spatial deficits, attentional deficits have received considerably less emphasis. However, studies have now documented that AD patients do show significant attentional impairment (Cossa, Della Salla, et al. 1989; Nebes and Brady, 1989; Perry and Hodges, 1999; Parasuraman, Greenwood, Haxby, and Grady, 1992), and that these deficits emerge very early in the course of the disease (Perry, Watson, and Hodges, 2000). While sustained and focused attention appear less affected, divided and especially selective

attention are clearly more compromised (Foster, 2001; Parasuraman and Haxby, 1993; Perry and Hodges, 1999). The underlying neurobiology of AD helps to explain why there are localized attentional deficits: both the distribution of these neuropathological changes and the neurochemistry of the disease cause disruption of specific attentional mechanisms.

Neurobiological Bases of Attentional Changes in Alzheimer's Disease

The neuropathological changes in AD include primary cell loss (Terry, 2000), neuritic plaques (Braak and Braak, 1991), and neurofibrillary tangles (Braak and Braak, 1995) in the basal forebrain (Davies and Maloney, 1976; Whitehouse et al., 1981, 1982), hippocampus, entorhinal cortex (Killiany et al., 2000), and infero-lateral temporal, inferior parietal, anterior and posterior cingulate, and ventral frontal cortices. Functional imaging corroborates the changes in these areas in AD. PET studies have shown hypometabolism of glucose (Alavi et al., 1986; Haxby et al., 1985, 1986) in the inferior and posterior parietal cortex, and reduced regional cerebral blood flow (Montaldi et al., 1990) in the parietal, frontal, and temporal cortices in AD patients. Kastner and Ungerleider (2000), using specific selective attentional tasks in controls, showed definite fMRI variations involving the V4/parietal regions, that is, those areas precisely affected by neuropathologic AD changes. Thus, the high density of abnormal pathologic changes and the impaired glucose metabolism are distributed in, and overlap with, those areas believed to be responsible for mediating attentional functions (Mesulam, 1981; Posner and Petersen, 1990).

This neuropathology of AD specifically affects pyramidal cells and cells in laminar layers II, III and IV of the cortex (Morrison, et al., 1986). Cortico-cortical fibers emanate from layers III and IV, forming the anterior-posterior tracts that connect frontal and parietal cortical association areas. Parasuraman and Haxby (1993) have proposed that the distribution of this laminar pathology disconnects the anterior and posterior attentional networks. This disconnection is another underlying mechanism of the attentional deficits seen in AD.

Attentional deficits in AD also stem from the neurochemical changes of the disease. Specifically, the loss of cholinergic innervations from the basal forebrain to the hippocampus, amygdala, and cortex (Bartus, Dean, Beer, and Lippa, 1982; Geula and Mesulam, 1995) reduces total available acetylcholine. The role of acetylcholine in attention (Sarter and Bruno, 1997), and the effect of cholinergic depletion on attention, have therefore been of great interest in AD (Lawrence and Sahakian, 1995; Sarter, 1994). Davidson and Marrocco (2000) showed specific deficits in covert cueing when monkeys were administered a cholinergic antagonist, scopolamine, demonstrating direct effects of cholinergic depletion on the attentional mechanism. Other experiments showed that in rats, scopolamine increases RT and increases errors on a visual response task (Mirza and Stolerman, 2000), and increases omission and commission errors on a signal detection task (Bushnell, Oshiro, Padnos, 1997). In humans, administration of scopolamine shows dose-dependent anticholinergic side effects, amnestic changes, and importantly, reduced alertness and omission errors on a letter cancellation task (Parrott, 1987). The effects of

cholinergic depletion in AD on attentional function have therefore received particular interest (Lawrence and Sahakian, 1998; Sahakian et al., 1993). A recent PET study (Shinotoh et al., 2000) showed a progressive loss of acetylcholinesterase in AD (suggesting a loss of the ascending cholinergic system), which corresponded to gradual cognitive decline. While the newer acetylcholinesterase inhibitors have demonstrated global improvements (Rogers and Friedhoff, 1996; Rösler et al. 1999; Tariot et al., 2000), these medications could have a more marked effect on attentional skills.

In summary, the neuropathologic distribution, the intercortical connections between attentional networks, and the neurochemical changes in AD support the view that alterations in attention can be seen as a function of the disease. Thus, research using several paradigms has demonstrated compromised selective attention function in AD patients. These studies will be reviewed. It is also important to recognize that the paradigm used can further elucidate why the patients are impaired: whether the dysfunction is simply a decrease in speed, supporting the aging hypothesis in AD (Salthouse and Somberg, 1982), or whether AD patients show deficits that are qualitatively distinct which would implicate a disruption or dissociation of other aspects of the attentional substrate. The following section will review relevant research in this area.

Manipulations of Selective Attention Tasks in Alzheimer's Disease

Among the attentional deficits in AD that have been documented, selective attention appears to be most vulnerable. Selective attention tasks tap many different

functions, each of which may pose difficulty for these patients: patients with AD may show completion time deficits because their approach to these tasks is effortful, not automatic (Hasher and Zacks, 1979); deficits in AD may be due to poor target detection, particularly if they are less able to discriminate stimuli; deficits may also be a function of the inability to recognize the different levels of demands for the task (e.g. serial versus parallel, or set size), and adjust or switch attentional allocation accordingly. As a consequence, inaccurate or slowed performance could be indicative of inefficient use of available capacity, poor ability to adjust the allocation according to the demands of the task, or perhaps an impaired or reduced overall capacity. Finally, deficits in inhibition (Stuss et al., 1995) are critical in the need to suppress nontargets. In summary, selective attention tasks require multiple skills, including disengagement, shifting, suppression of distractors, discrimination, and target detection, all of which vie for attentional resources. One explanation of the deficits is that AD patients can allocate attention only in situations where task demands do not exceed available capacity (e.g., simple feature searches). The amount of attentional effort that a task requires, its demand on available resources, has been referred to as its perceptual load (Kahneman and Treisman, 1984; Lavie and Tsal, 1994). As load demands increase, processes such as speed and switching resources become more susceptible to dysfunction. Varying the task load should reveal whether these and other attentional processes become vulnerable in these patients in ways different from their healthy control counterparts. Examples of load variations include performance on low load tasks (e.g., simple feature searches), and the effects of

manipulating load on tasks of conjunctivity, set size, and physical similarity between stimuli. These will be reviewed.

Simple Feature Search

The ability of patients with AD to perform a low-load feature search appears to remain intact. A simple feature search is one in which subjects can preattentively detect a target in parallel by analyzing only one feature of the stimulus, thus placing no or fewer demands on the attentional system (Treisman and Gelade, 1980). These so-called "pop out" searches are the easiest, since stimuli differ dramatically by one feature, such as color. Nebes & Brady (1989) compared healthy young and elderly adults with AD patients on a task in which half of the presentations had six black letters and the other half had four red and two black letters, from which subjects were told to specify the black target letter. Both control and AD subjects searched the array faster when the color of the letters allowed them to limit the search to 2 black letters. Therefore, they concluded that AD patients appeared to be relatively unimpaired when an object feature (such as color) limits the search to only relevant stimuli. This was replicated in other studies (Parasuraman, Greenwood, and Alexander, 1995; Greenwood, Parasuraman, and Alexander, 1997), which compared simple feature search conditions (color alone) to conjunctive conditions (letter as well as color).

But while simple feature search is preserved in AD, the location of the target within the visual field may compromise this ability. Comparisons of RT when targets were presented in the periphery versus when they were presented centrally showed poorer

performance in the periphery, and this effect increased with increasing severity of AD (Foster et al., 1999). These results suggest that, within simple feature search, there may be an interaction between detection and ability to shift attention. While intact discrimination may be mediated by primary cortical visual areas that are known not to be affected by AD pathology (Braak and Braak, 1991, 1995), the impaired search in the periphery may involve the parietal association regions that are affected by the disease and emerge as a more subtle finding in neglect (Ishiai et al., 2000).

Conjunctive Search

In conjunctive tasks, the target shares features with the distractors (Treisman and Gelade, 1980), demanding more resources and placing a greater load on the attentional system. Studies have shown disproportionate slowing on conjunctive tasks among AD subjects. Parasuraman et al. (1995) compared feature search and conjunctive search in a task that also tapped cued covert-orienting skills. In the simple feature search, the target was discriminated solely by its unique color. In the conjunctive search, one third of the distractor letters shared a color with the target and one third shared a letter, but only the target possessed both properties. Results indicated that the simple feature search remained preserved in AD, whereas in the conjunctive search, AD patients were slower to detect the target than controls. This was confirmed in a later study (Greenwood et al., 1997), always noting that it was the speed of performance that was vulnerable.

While AD patients are slower on conjunctive tasks, studies have also revealed an interaction between conjunctive search and covert orienting. For control subjects, a

valid-cue condition (in which a cue directs attention to the correct target location) enhances conjunctive search since subjects are directed to the location of the target; valid cues do not also affect completion time during a simple feature search since the target already pops out (Posner, 1980). Similarly, in searches incorporating a conjunctive discrimination task, AD patients' performance also improves in the valid cue condition (Greenwood et al., 1997; Parasuraman et al., 1995). Thus, by directing attention to a location, enough attentional resources are spared in AD to be used to perform the more demanding conjunctive task.

Recent studies by Foster (Foster et al., 1999; Foster, 2001) also showed disproportionate slowing on conjunctive versus simple feature search tasks in AD subjects. Again, several aspects interacted with conjunctivity. Using a computerized visual search paradigm composed of simple feature and conjoined feature tasks, Foster and colleagues (1999) varied target laterality (left vs. right) and target location (central, intermediate, or peripheral). Targets in the conjunctive condition were detected faster on the left than those presented on the right, and this was most pronounced among the AD subjects. Results were interpreted as supportive of right hemisphere dominance in attention, or that there might be delayed interhemispheric transfer in AD. In addition, targets in the conjunctive condition were detected faster in the central location than in either intermediate or peripheral locations. This is similar to the findings of the simple feature search condition, and could be attributed to constriction of the perceptual window

(Foster et al., 1999), or again may reflect poorer performance among AD patients when required to reallocate attention to other areas of the visual field.

In sum, the above studies have demonstrated that AD patients show disproportionately slow performance during conjunctive visual search tasks (Foster et al., 1999; Greenwood et al., 1997; Parasuraman et al., 1995), which may be the result of the greater load placed on the attentional system by these types of tasks. These studies also showed that AD patients benefit from having prior attention directed toward the target location, whether from an externally presented cue or from already focusing on the central portion of the visual field. Both instances efficiently utilize their limited attentional resources.

Brain imaging data further support the notion that conjunctive search, as opposed to simple search, requires more involvement of higher cortical association regions that are vulnerable in AD. PET data from controls (Corbetta, Shulman, Miezin, and Petersen, 1995) showed superior parietal cortex activation during a conjunctive task, but not during a simple feature search. The conjunctive search of an array also precipitates significantly enlarged event-related brain potentials (ERPs) in the posterior parietal region (P1) as compared to other brain regions (Luck, Fan, and Hillyard, 1993), although this was not directly contrasted with the simple feature search condition. In short, measures of brain activity implicate the involvement of posterior parietal areas during conjunctive tasks, which are especially vulnerable in the AD population (Alavi et al., 1986; Haxby et al., 1985, 1986; Montaldi et al., 1990).

Similarity

The load of a search can also be made more difficult by increasing the similarity of the physical features between target and distractors (Duncan and Humphreys, 1989). Increased similarity between stimuli incorporates the notion that visual discrimination is made more difficult and any chance of 'pop-out' is minimized. If the similarity between target and distractors increases, the amount of bottom-up activation of the target is decreased and search becomes slower and less accurate (Wolfe, 1994,1996a, 1996b).

The idea that increased similarity between stimuli makes a task more difficult has been addressed in both young and older subjects, as well as in patients with AD. For instance, in computerized visual search studies that systematically varied the degree of physical similarity between target and distractor, RT was slower and accuracy lessened with high similarity as opposed to low similarity for both elderly (Scialfa and Harpur, 1994; Scialfa, Esau, and Joffe, 1998) and young subjects (Hammar et al., 1998). Geldmacher (1998) found increased similarity difficult for young subjects, even on a cancellation task that involved the search for many targets. A study by Rapcsak and colleagues (Rapcsak, Verfaellie, Fleet, and Heilman, 1989) tested brain damaged patients with neglect (i.e. right parietal lesion) using a cancellation task. Three conditions in the study included one with only targets, one with a target and a non-target (pop-out), and one with a target similar to the distractor foils (serial search condition). The neglect patients made more omissions (field effect), but only in the condition where the target was presented with similar foils. The effect of commissions was significant when

comparing the pop-out to the serial condition, suggesting that only the serial search precipitated the false alarms. There was no visual field effect for the commission errors. Of note was that the field effect was only evident in the serial condition, showing that in the simple detection or pop-out condition, the attentional bias to one side of space is not elicited. Thus, the increased load of searching for a target among similar distractors led not only to increased errors, but also to a visual field effect of omitting targets on one side of space.

In AD patients, Foldi et al. (1992) found that overall commission errors were not significantly greater in the AD subjects compared to the depressed or healthy counterparts. However, analysis showed that when AD subjects did make these errors, there was a significant bias to cancel those distractors that shared some feature with the target (e.g., choosing ovals for circles). That is, the similarity of the distractors made them harder to inhibit or discriminate. Amieva and colleagues (Amieva, Lafont, Dartigues, and Fabrigoule, 1999) found that when targets and distractors varied only by one feature, the number of commission errors as well as omission errors in AD patients increased. The cancellation task used was an abridged version of Zazzo's cancellation task (see Zazzo, 1951, as cited in Amieva et al., 1999). The targets (squares with a small line on top), varied from the distractors (squares with small lines on either side) because of the placement of a line. Results indicated that AD subjects made significantly more omissions and commission errors compared to controls. The authors attributed the greater number of commission errors to the fact that the target and distractors were more

physically similar, requiring more inhibitory processes in order to suppress canceling the distractors. However, one criticism of the study by Amieva et al. (1999) is that it used an orderly-array type of cancellation test (in which stimuli are arranged in an organized fashion of rows and columns), which may have driven subjects to scan the field systematically (row by row), as opposed to using their own search strategy. This may have also had the effect of making the task easier by reducing the need to allocate attention to the search mechanism. A recent study by Gainotti, Marra and Villa (2001) also demonstrated increased commission errors among AD patients on a cancellation test with similar distractors, as compared to both controls and patients with multi-infarct dementia (MID). Both patient groups had fewer hits than controls, but AD patients did not differ from MID patients on this measure. The cancellation task used in this study consisted of finding a target (square with two inside lines, one on the bottom and one in a corner) among distractor squares, each containing variously oriented lines. As in the Amieva et al. (1999) study, the authors of this study attributed the greater commission errors among AD patients to impaired inhibitory mechanisms. In another recent study of similarity in AD patients, Baddeley and colleagues (Baddeley et al., 2001) compared AD patients to elderly and young controls on a search task in which subjects were instructed to cancel letter "Z's" imbedded among rows of either curved letters or other angular letters. They measured search time and numbers of omission and commission errors. They found that AD patients were more susceptible than controls to the similar distractor letters, with increased search time and number of omission errors, however commission

errors in this study were too rare to analyze. Like the Amieva et al. (1999) study, this study also used an orderly-array type of cancellation test, and thus may not have encouraged subjects to use their own search strategy.

Thus, in past experiments involving physical similarity between target and distractors (Amieva et al., 1999; Baddeley et al., 2001; Gainotti et al., 2001; Geldmacher, 1998; Hammar, 1998; Rapcsak et al., 1989; Scialfa, Esau, and Joffe, 1998; Scialfa and Harpur, 1994), a variety of subjects have demonstrated an increase in errors when the target and distractors were similar. These results support aspects of the feature-integration theory (Treisman and Gelade, 1980; Duncan and Humphreys, 1989). Of these studies, only those by Amieva et al. (1999), Baddeley et al. (2001), Foldi et al. (1992) and Gainotti et al. (2001) involved AD patients, however, and none of these systematically varied the degree of physical similarity. Therefore, it is not known whether an increase in stimulus similarity would precipitate a breakdown in the attentional mechanism of AD patients that would be seen not only in longer completion times, but also in reduced accuracy. Consequently, a study is needed that gradually increases the physical similarity between target and distractors.

Set Size

Another way to manipulate the load of the attentional system is to manipulate the quantity of information being presented at any given time. There are several ways to change the quantity. One is to increase the size of the display, as Santostefano (1978) did by presenting cancellation tests on varying sizes of paper. Secondly, the quantity of the

array can be diminished by the so-called 'spotlight effect,' where the subject is directed to attend to a target only in certain sections of the array (Posner, 1980; Eriksen and Yeh, 1985; Posner and Presti, 1987; LaBerge and Brown, 1989). This method was used with AD patients (Parasuraman et al.,1995), who were presented an array and asked to find the target within rectangular boxes of various sizes (the size of one letter, two letters, or the entire array). The speed of this conjunctive search was affected by box size, being slowest when the entire array was included and fastest for the smallest, most precise box. A third way to manipulate quantity is to change the density of the stimuli within the array: when display size stays constant and the number of items increases, then the set size (or density) has increased. As mentioned earlier, serial tasks are affected by set size, whereas parallel searches are not (Neisser, 1967; Schneider and Shiffrin, 1977; Treisman and Gelade, 1980).

A number of studies have examined the effect of increasing set size in AD patients in order to study attention in AD. In a cancellation task, Foldi et al. (1992) varied the total number of items in the field (density), as well as the number of different types of distractors in the surround (complexity), in order to determine if AD patients were more vulnerable than controls to increased load. All subjects (AD patients, age-matched controls and depressed patients) showed more omission errors as density increased, with a trend for the AD patients to be most sensitive to the density change. Omission errors correlated with AD severity, with the higher density eliciting disproportionately more omission errors. The authors concluded that the AD subjects

were overwhelmed by the increased quantity of information, but not by the changing quality of the surround. Foster et al. (1999) varied set size in both simple feature search and conjunctive search tasks by increasing the number of distractors in the array. The set sizes altered performance only in the conjunctive search condition: completion time on target hits of AD patients on the conjunctive task increased disproportionately with increased array size. The authors attributed these deficits to the increased processing demands of the combination of higher set size and conjunctivity.

However, while prior studies have indicated that AD patients' performance on a task deteriorates with the presentation of increased quantities of information, there is a confounding factor when considering density. Specifically, one needs to determine whether the ratio between targets and distractors plays a role in performance on these cancellation tasks. That is, when the number of targets surpasses the number of distractors or, conversely, when the distractors exceed the targets, the attentional capacity may be affected differentially.

Some studies confound density, or set size, and target-to-distractor ratio. For example, in a study of neglect patients (Kaplan et al., 1991), a right visual field bias was observed only when distractors exceeded targets. However, the increase in number of distractors (while keeping target number constant) not only changed the target-to-distractor ratio, but also the density of stimuli in the field. In AD studies, Foldi et al. (1992) and Foster et al. (1999) also confounded ratio and density.

Several studies with healthy controls (Bacon and Egeth, 1997; Geldmacher, 1996; Geldmacher and Hills, 1997) have begun to disentangle this issue of the role of ratio, vis-à-vis density. These studies investigated whether target detection was harder as a function of increased set size, or when there was more to inhibit (as is the case when there are more distractors in the surround). Geldmacher (Geldmacher, 1996; Geldmacher and Hills, 1997) found that when there were fewer distractors (target-to-distractor ratio = 1:4), target omissions were fewer than when distractors were abundant (target-to-distractor ratio = 1:9), keeping the set size constant. There was no condition in these studies, however, that reversed the target-to-distractor ratio, such that the number of targets was larger than the number of distractors. Moreover, there was no indication whether the error pattern changed as a function of this ratio; specifically, whether patients resort to more commission errors as the surrounding numbers of distractors increases. If this were the case, impaired inhibition and/or discrimination could explain the performance difficulty. Another explanation for the difficulty searching in different locations of the array is that the locus in the visual field can also interact with the ratio pattern. This has not been studied in AD. For instance, do AD patients make omission errors of targets that are presented outside the central visual area only when the ratio or the density is high?

A change in ratio can also change the number of the targets to be selected. Della Sala, Laiacona, Spinnler, & Ubezio (1992) did not specifically manipulate ratio as a variable, but in their digit cancellation task they increased the number of targets from one

to three, thereby also changing the ratio. Both AD and controls made more errors (hits minus false positives) when the number of targets increased, but the significant condition x group interaction indicated that AD patients had disproportionately greater difficulty as the required target cancellation increased. The AD subjects deteriorated significantly when required to cancel two targets. These findings can be interpreted as an effect of ratio, or it may be indicative of the greater demands placed on the capacity to maintain and switch three different targets simultaneously. It should be noted that while this study did incorporate the effect of false positives, the use of a combined dependent variable in this task could not differentiate between the types of errors (omissions versus commissions) as a function of the increased demands.

Thus, while the effects of target-to-distractor ratio (Foster et al., 1999; Geldmacher, 1996; Geldmacher and Hills, 1997; Kaplan et al., 1991) suggest that errors increase when distractors exceed targets, only the Geldmacher (1996) and Geldmacher and Hills (1997) studies specifically varied target-to-distractor ratio while keeping density constant (although not with AD subjects). The confounding of density and ratio has not been disentangled, nor have the types of errors been differentiated. A study that addresses these issues is needed. If errors in AD are due predominantly to disinhibitory mechanisms, conditions where distractors outnumber targets should elicit more commission errors. Alternatively, when targets outnumber the distractors, the tasks required to discriminate, detect, and scan across the visual field become more challenging, and place greater demands on capacity. Hence, omission errors are more

likely. Again, the effect of ratio would have to be distinguished from the effect of increased load due to larger set size.

Objectives of the Current Study

The purpose of the present study was to examine the effect of a systematic increase in load on visual selective attention in Alzheimer's disease. The study was designed to measure both the qualitative and the quantitative performance of AD patients, as they are exposed to increasingly demanding visual arrays. Three different types of load were chosen: stimulus similarity (Similarity), set size (Density), and the degree to which stimuli stand out from their surround (Target-to-Distractor Ratio). The study predicted that the attentional deficits in AD are not simply a reflection of cognitive slowing (Salthouse, 1985), but an impairment in strategy in dealing with increased load, which would be reflected in the interaction of speed and error type. Therefore, in order to assess how AD patients are different from elderly controls, measurements of speed (completion time), accuracy, as well as error type (omissions and commissions) were analyzed. Specifically, while selective attentional deficits in AD have already been described in numerous studies, a progressive modification of attentional demands and the resulting qualitative and quantitative responses to those demands has yet to be documented.

Independent Measures to Alter the Load of the Selective Task

The study proposed to investigate three physical variables to alter the display: Similarity between target and distractors, Density, and Target-to-Distractor Ratio. Each

variable was systematically varied in order to increase the load of the task demands, by creating successive levels of difficulty. Experiment 1 investigated the Similarity and Density variables, and Experiment 2 investigated Density and the Target-to-Distractor Ratio variables.

Physical Similarity

Increasing the Similarity between targets and distractors makes a search more demanding since it forces the subject to perform a conjunctive and serial search task (Treisman and Gelade, 1980). AD patients have been shown to be impaired on conjunctive tasks (Foster et al., 1999; Greenwood et al., 1997; Parasuraman et al., 1995), while unimpaired in performing parallel tasks (Nebes and Brady, 1989).

Again, while previous studies have looked at the effects of similarity between target and distractors (Amieva et al., 1999; Baddeley et al., 2001; Gainotti et al., 2001; Geldmacher, 1998; Hammar, 1998; Rapcsak et al., 1989; Scialfa, Esau, and Joffe, 1998; Scialfa and Harpur, 1994), none has examined similarity in a systematic fashion with AD patients. In all of these studies, the stimuli used were known, categorizable, and easily labeled, such as letters (Baddeley et al., 2001; Geldmacher, 1998; Hammar, 1998), shapes (Foldi et al., 1992), or modifications of shapes, such as squares with lines (Amieva et al., 1999; Gainotti et al., 2001), a bisected circle (Scialfa, et al., 1998; Scialfa and Harpur, 1994), or boxes with colored squares (Rapcsak et al., 1989). In these studies, bottom-up processing could be overridden by top-down semantic labeling of the stimuli.

Prior studies also have not specifically investigated the qualitative responses of AD patients to physical similarity via an analysis of error type (both omission errors and commission errors). While Geldmacher (1998) found that young controls made more omissions errors when targets were physically similar to the distractors, he did not analyze for commission errors. Hammar et al. (1998) reported that the most similar distractor type caused the fewest hits and the longest completion time in controls, but omission and commission errors also were not analyzed. In AD patients, both Foldi et al. (1992) and Baddeley et al. (2001) found very few commission errors. A study by Amieva et al. (1999) did find that similar distractors caused both omission and commission errors in AD patients, but with only one distractor type, the load was not increased incrementally. Similarly, Gainotti et al. (2001) found increased commission errors, and comparable hits, in AD patients as compared to MID patients, but also did not systematically vary similarity among distractors.

The current study sought to investigate the effect of increased load on the attentional system in AD by manipulating the Similarity between targets and distractors. For the current study, Similarity between target and distractor was operationally defined as the degree to which stimuli shared physical features. Three gradations of Similarity were created by having stimuli share increasing numbers of features. The distractors varied on a continuum from least similar (low load) to most similar (high load) to the target, and were empirically determined from the pilot study to a) be increasingly more different from the target, and b) vary in equal increments. Pop-out and disjunctive tasks

were included as controls. The present study was designed to test the visual aspect of Similarity with stimuli that were novel and non-verbal, without obvious semantic labels. By avoiding letters or shapes, the task became a forced bottom-up search, providing a more direct measurement of the effect of load. Qualitative changes in response strategy of AD patients to increased load were demonstrated by analyzing completion time and error type (both omissions and commissions).

It was predicted that, as Similarity increased, AD patients and controls would show differential responses of completion time and error. While both groups would take longer as Similarity increased, AD patients were expected to make significantly more errors of omission and commission as the Similarity increased.

> HYPOTHESIS (1): As the Similarity of the distractors to the target increases, both AD patients and controls will have longer completion times, and make more errors of both commission and omission (main effects). It is anticipated that the AD patients will be differentially affected by the increased similarity, with longer completion times and more of both types of errors (Similarity x Group interaction) at the highest level of similarity.

Density

Increasing the number of items in an array is another means of taxing the attentional resources of the system. As was cited previously, studies (Foldi et al., 1992; Foster et al., 1999; Greenwood et al., 1997; Nebes and Brady, 1989; Parasuraman et al.,

1995) have shown that AD patients are adversely affected when they have to search for a target among larger numbers of items. When the number of items within a given display size increases, then the density has increased.

If higher density commands more attentional resources, poor allocation of these resources leads to error. The objective of this study was to show that increased Density adversely affects AD patients as it represents another measure of load on the attentional system. It was expected that AD patients, compared to controls, would respond more sensitively to the changes of Density as was observed in prior experiments (Foldi et al., 1992; Foster et al., 1999). The speed - accuracy tradeoff for density was not investigated previously, and could be used to explore the effects of changes in quantity of information. It was predicted that completion time would increase, not just because of the increased number of items to be processed, but also to increased time per item.

Therefore, while an increase in completion time as a result of increased Density was predicted for both groups, AD subjects were expected to take disproportionately longer than controls to complete the cancellation tests as Density increased. Given that studies have shown that increasing density adds to the number of omission errors (Foldi et al., 1992), it was expected that both groups would omit targets as a function of Density. Further, while it was anticipated that both groups would make commission errors as a function of Density, AD patients were expected to demonstrate more such errors.

Since Physical Similarity was varied along with changes of Density, an interaction between Density and Similarity was also expected. If increasing Density *and*

Similarity further increases load, both groups should respond to this increase in load with increased completion time. However, accuracy is likely to vary between the two groups, with AD subjects more vulnerable to commission errors since more inhibition is required.

HYPOTHESIS (2): As the Density increases, both AD patients and controls are predicted to have longer completion times, but AD patients are expected to be disproportionately affected. Error analysis will determine whether the longer time to perform the search affects accuracy. It is anticipated that AD patients will produce more commission errors than controls (Group x Density interaction), but not more omission errors.

Further, it is expected that increasing both Density and Similarity will affect both AD patients and controls with increased completion times. Again, it is anticipated that the AD patients will be especially affected in regard to commission error types (Group x Density x Similarity interaction) as compared to accuracy rates.

Target-to-Distractor Ratio

Another way to increase load in the present study was to manipulate the Target-to-Distractor Ratio (TDR). The relative number of one stimulus (e.g., target) compared to the other (e.g., distractor) alters the salience of the stimuli, and changes which stimulus is viewed as "figure" and which is viewed as "ground." When many targets have to be searched, more shifts of engagement and disengagement are needed. In conditions where

there are many distractors relative to targets, more inhibition is needed to suppress responses to the nontargets.

Most studies have confounded target-to-distractor ratio and density of items on a page, and no investigators in AD have manipulated target-to-distractor ratio while keeping density constant. Studies that have confounded target-to-distractor ratio and density include one by Kaplan et al. (1991) in neglect patients, and two in AD patients (Foldi et al., 1992; Foster et al., 1999). Two studies by Geldmacher (Geldmacher, 1996; Geldmacher and Hills, 1997), which included healthy young adults, found an effect of target-to-distractor ratio while controlling for density, with an increase in omission errors with a higher proportion of distractors. However, these studies did not assess commission errors. In AD patients, Della Sala et al. (1992) systematically increased the number of targets, keeping density constant, thus altering the target-to-distractor ratio. They found that AD patients made more errors (hits minus false positives) with increased number of targets, but the study did not specifically indicate any commission errors. Neither Geldmacher (Geldmacher, 1996; Geldmacher and Hills, 1997) nor Della Sala et al. (1992) demonstrated the condition where targets outnumbered distractors.

The objective of the current study was to demonstrate that variations of the Target-to-Distractor Ratio could be used to investigate the qualitative effects of load. In order to test the effect of Target-to-Distractor Ratio, the proposed experiment altered the number of distractors relative to targets over 5 levels, within three levels of Density. It was predicted that error patterns would vary with ratio. As the number of targets

increased, the AD subjects would be increasingly prone to omission errors, even as they are likely to take longer for the search. Deficits in inhibition would likely affect AD patients only when the interference of the surround (e.g., higher number of distractors than targets) became apparent. We would therefore predict that rates of errors of commission would increase as distractors outnumbered targets.

Since varying the ratio (or proportion of distractors) occurred along with changes of Density, an interaction was also expected. Again, the AD group was expected to be disproportionately affected compared to controls, with increased completion time and errors of commission. Thus, an interaction between Target-to-Distractor Ratio and Density was predicted for all outcome measures, as well as a Group x TDR x Density interaction effect.

> HYPOTHESIS (3): As the number of distractors exceeds the number of targets, both AD patients and controls will have longer completion times, but AD patients will make more errors of commission (Group x TDR interaction).
>
> As the number of targets exceeds the number of distractors, both AD patients and controls will have longer completion times, and AD subjects are more likely to make more errors of omission (Group x TDR interaction).

Further, it is predicted that higher levels of Density will exacerbate the AD patients' inability to inhibit distractors (Group x TDR x Density interaction).

EXPERIMENT 1

Method

In Experiment 1, the primary variable of interest was the effect of Physical Similarity between the target and distractors on performance for AD patients and controls. Three variables were manipulated: Similarity, Density, and Complexity, in order to investigate the effect of changes in physical characteristics of a visual search task on selective attention in AD patients.

Participants

Patients (N = 15) with the diagnosis of probable Alzheimer's Disease (AD) were selected from a pool of patients referred to the Neuropsychology outpatient service or the outpatient Geriatric service at Winthrop-University Hospital for evaluation of dementia. The subjects were assessed for probable AD according to the criteria of the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's disease and Related Disorders Association (NINCDS/ADRDA) guidelines (McKhann et al., 1984), which requires an interview, neuropsychologic, neurologic and neuroradiologic assessments, and full laboratory screens to rule out other causes of the putative dementia. All subjects were evaluated by a neuropsychologist and a physician.

Subjects had to meet neuropsychological criteria of Mini- Mental Status Exam (MMSE) Score < 26 (Monsch et al., 1993) and/or Dementia Rating Scale (DRS) < 130 in order to be considered patients with probable AD. Neuroradiologic information (CT or MRI) further supported exclusion of vascular dementia or tumor etiology, and was done for all patients.

Control subjects (n = 15) were recruited from a pool of individuals in the local community, or were spouses of the probable AD subjects. Subjects from the community were recruited at educational senior programs; they were invited to participate in cognitive research and indicated their interest in the program. A telephone screening interview was conducted to determine the subject's age and information about the following exclusion criteria: any past or present history of neurologic or psychiatric disease, alcohol or substance abuse, severe head trauma, or ongoing treatment for any medical illness that could affect cognitive function (e.g., cardiac disease, diabetes). Once they met inclusion criteria and agreed to participate, subjects were assessed by use of the MMSE to rule out dementia (MMSE Score ≥ 26; Monsch et al., 1993).

Both groups of subjects were drawn from the same community, and equivalent mean age groups were achieved. Means and standard deviations are given for age and education in Table 1.

Table 1: Demographics of Subjects in Experiment 1.

	AD 1			Controls		
	range	mean	sd	range	mean	sd
age (yr)	55-83	75.4	8.11	64-86	74.91	6.11
education (yr)	8-19	13.31	3.21	8-20	14.71	3.01
MMSE	12-26	21.53	3.68	27-30	28.73	0.80
gender	11 females; 4 males			11 females; 4 males		
handedness	13 right; 1 left; 1 ambidextrous			14 right; 1 left		

All subjects gave consent to participate in the study (see Informed Consent, Appendix C), and were paid $35 for their participation. For AD subjects, a family member, responsible party, or, if appropriate, legal guardian also gave consent. The study was approved by the Institutional Review Board of Winthrop-University Hospital.

Stimuli

Target and distractor stimuli were novel designs produced using Harvard Graphics 3.0 (Software Publishing Corporation, 1991-1994). Stimuli were black line drawings, 2 cm^2 in size.

Cancellation tests were designed on 8 1/2 x 11 inch pages of white paper, and contained both targets and distractors. The same target stimulus was used throughout. A pilot study was conducted to choose the three sets of distractors out of eleven that were to be used in the cancellation tests (see Appendix B). The purpose of the pilot study was to provide an empirical basis for choosing the most equivalent stimuli along the dimensions of physical similarity and ordinal position. Cancellation tests were produced using Microsoft PowerPoint (Microsoft Corporation, 1987-1996).

Distribution of Stimuli

In Experiment 1, Density, or the number of items on a page, was varied across three levels, while keeping the target-to-distractor ratio constant at 1:3. Varying the density results in the number of targets and distractors per page shown in Table 2.

Table 2: Number of Targets and Distractors at Varying Levels of Density.

Density Level	Stimuli per Page	Targets	Experimental Distractors
1	16	4	12
2	32	8	24
3	48	12	36

Stimulus Placement

Targets and distractors were distributed equally in each of the four visual field quadrants of the 8 1/2 x 11 inch page. Placement of the stimuli was facilitated by a computer program designed by John Zhu, M.A., which randomly generated X,Y coordinates. These coordinates were then used in Microsoft PowerPoint to place the actual illustrations, leaving a random amount of distance between any two contiguous stimuli. Targets were placed first in each quadrant using the coordinates, followed by the distractors.

Complexity, the number of different types of distractors that are included on a page, was either 2 or 3. When Complexity = 2, the two types of distractors included in each cancellation test had to be chosen; Table 3 was used to determine which combination of distractors (X & Y, Y & Z, X & Z) would be used at that Density and

Similarity level. When Complexity = 3, all three distractor types (X, Y, and Z) were used.

Table 3: At Complexity = 2, Combination of Distractors Used at Each Level of Similarity and Density.

Similarity 1	Similarity 2	Similarity 3	
1X and 1Y	2X and 2Z	3Y and 3Z	Density 1 (16)
1X and 1Z	2Y and 2Z	3X and 3Y	Density 2 (32)
1Y and 1Z	2X and 2Y	3X and 3Z	Density 3 (48)

Two sets of random numbers were generated using the Quatro Pro 6.02 program (Corel Corporation, 1996) to determine which distractor (X, Y, or Z) to use when the Complexity was 2 or 3. For Complexity = 2, the random number table of 1-2 was used, for Complexity = 3, the random number table of 1-3 was used to determine the distractor type. Distractors for quadrants I through IV were placed in the same manner as above.

Procedure

Experiment 1 was designed as a series of cancellation tests (see Appendix A for a sample test). Each subject was seated in a quiet room with the examiner. All subjects were first given two brief Pre-tests to ensure that they were able to discriminate stimuli. In Pre-test A, subjects decided whether two illustrations in each of ten pairs were the same or different. In Pre-test B, subjects viewed nine sets of three illustrations and crossed off the one that was different. The stimuli used in these practice tests were different from those used in the experimental cancellation tests. If a subject could perform at least 80% correct on these pre-tests, they were given the experimental task interspersed with a battery of neuropsychological tests. To prevent fatigue in the AD

subjects (all of whom could not do 18 consecutive tests) and boredom in the controls, the cancellation tests were intermingled with the neuropsychological tests.

Both the probable AD and control subjects were given neuropsychological tests that assessed general cognitive functioning, as well as a number of tests to capture memory, language, executive functioning, and attentional processes specifically (see Table 4). These were administered during the same testing session.

Table 4: Neuropsychological Tests Administered, Grouped into Function.

Neuropsychological Test	Cognitive Function Assessed
Mini Mental Status Examination (MMSE; Folstein, 1975)	General Cognitive Functioning
Dementia Rating Scale (DRS; Mattis, 1988) Subtests: Attention, Initiation/Perseveration, Construction, Conceptualization, and Memory	General Cognitive Functioning
Boston-Rochester Neuropsychological Screen (BRNS, unpublished manuscript)	General Cognitive Functioning
California Verbal Learning Test- I (CVLT-I; Delis et al., 1987)	Memory
Boston Naming Test - 60 item version (BNT; Kaplan et al., 1983)	Language
Loops (Luria, 1966)	Executive Functioning
M&Ns (Luria, 1966)	Executive Functioning
Go-NoGo (R&L) (Luria, 1966)	Executive Functioning
Luria sequence (R&L) (Luria, 1966)	Executive Functioning
Rhythm test (4 rhythms) (Goodglass and Kaplan, 1983)	Executive Functioning
Trails-B (Army Individual Test Battery, 1944)	Executive Functioning
5-Point Test (Regard et al., 1982)	Attentional Functioning (generativity, executive function)
Trails-A (Army Individual Test Battery, 1944)	Attentional Functioning (speed and scanning)
Wechsler Memory Scale -Revised digit span subtest (forwards and backwards) (WMS-R; Wechsler, 1987)	Attentional Functioning (vigilance and working memory)
Wechsler Memory Scale -Revised visual span subtest (forwards and backwards) (WMS-R; Wechsler, 1987)	Attentional Functioning (vigilance and working memory)
Wechsler Adult Intelligence Scale - Third Edition digit symbol - coding subtest (WAIS-III; Wechsler, 1997)	Attentional Functioning (vigilance, set-shifting)

Line Cancellation test (Albert, 1973)	Attentional Functioning (scanning)

Probable AD subjects were tested before the controls on Experiment 1, in order to establish the matching age group. Two practice tests were administered to familiarize subjects with the test, and to ensure that they accurately understood and could perform the task. Each test was presented on a single page. The target shape, drawn on a separate card, was present, and remained below the cancellation task throughout the entire task, to avoid depending on the subject's memory of the target. The subject was instructed, "Please put a line through this picture whenever you see it on a page. Do this as accurately and quickly as possible." There was a time limit of five minutes per cancellation test, and the performance was timed by the examiner using a hand-held stopwatch. In addition, the experimenter reminded the subjects each time of the task, and cued them to the target. Experiment 1 consisted of 18 experimental cancellation tests. In addition, both experiments had 3 additional tests at level Complexity = 1, one at each level of Density, to serve as a control for disjunctive (i.e. pop-out) processing. Therefore, there were a total of 18 experimental tests plus 3 disjunctive controls in Experiment 1. The order of the presentation of each individual cancellation test was determined by quasi-random sequencing of the tests using a random number table. The control subjects were administered both Experiments 1 and 2.

Following Experiment 1, all subjects were given Post-tests A and B, which were the same discrimination tests as Pre-tests A and B; this time the stimuli used were the same as the experimental stimuli. The purpose of the post-tests was to ensure that

subjects were able to discriminate the actual stimuli used in the experimental cancellation tests.

In order to determine whether the probable AD subjects could rank the illustrations, subjects were then asked to rank-order the three distractors in terms of physical similarity to the target, and judge physical distance between each distractor and the target. This was a repeat of the pilot study procedure (see Appendix B). All experimental tests, including cancellation tests and pre- and post-tests, were administered during the same session.

Scoring and Analysis

Cancellation tests were scored for errors of omission and commission, and completion time. Neuropsychological tests were scored according to test instructions, and were normed according to age group.

Both errors of omission and commission were converted to percent score (by dividing omission errors by the total number of possible targets on a page, and dividing commission errors by the total number of possible distractors on a page). In order to allow for a more stable variance over a large range, minimizing the effect of outliers, percent errors were then transformed using the arc sine of the square root, and completion time was transformed by taking its log value. These transformed data were then used for the analyses of variance (ANOVA). The data presented in the figures are untransformed values. So as to determine if there were group differences in the tendency to make many cancellations on a page (correctly cancelled targets (hits), but also commission errors), a

separate dependent variable (total cancellations) was created by adding all hits to all commission errors. To examine whether manipulations of physical characteristics of a visual search task differentially affected the groups, the transformed data (percent errors and completion time) and total cancellations were analyzed using separate 4-way repeated-measures ANOVAs, using the factors Group (2), Similarity (3), Density (3), and Complexity (2). In order to determine whether there was a bias to cancel more items in any one quadrant, separate 2-way repeated-measures ANOVAs (Group (2) and Quadrant (4)) were performed on transformed percent omissions and transformed percent commissions. An alpha level of .05 was used for all statistical tests.

Since the order of presentation of the tests was the same for all subjects, separate 2-way repeated-measures ANOVA (Group (2) and Order of Presentation (18)) for percent omission errors and percent commission errors were performed to determine whether the sequence of the administration (order presentation effect; i.e., comparing each subject's order of presentation) affected performance. Further, autocorrelations were conducted to confirm that there were no adjacency effects (i.e., influence of one test on subsequent test or tests).

To ascertain whether there was a relationship between experimental test performance and cognitive function, pair-wise correlations were conducted between the cancellation tests and tests of dementia severity (i.e., DRS), attention, memory, language, and executive functioning. Omission and commission error rates, and completion time, were analyzed separately for the AD and control groups. Spearman's nonparametric rank

correlation coefficient was used for all the correlations because of its insensitivity to outliers. (Spearman correlation values are equivalent to the (more usual) Pearson Product-Moment correlations computed on the ranks of the data rather than on the actual data values).

Computing large numbers of correlation coefficients increased the possibility of chance occurrence of spuriously significant values. To guard against this, a Bonferroni adjustment was used, whereby the conventional threshold significance p-value of 0.05 was reduced in proportion to the number of correlation coefficients compared in each analysis. Column 2 of Table 5 below shows the Bonferroni-modified significance probabilities (e.g. (Row 1) if 7 Rho values are involved, a critical p-value of 0.007 (=0.05/7) is used). Corresponding critical values of the correlation coefficient were used.

Results

Overall, results for Experiment 1 indicated that the AD group had longer Completion Times than controls when either Similarity or Density increased. In addition, AD subjects also made more Commission Errors as a function of increasing Similarity.

Analyses of Variance

Four separate 4-way repeated-measures ANOVAs were performed, one for each dependent variable: Total Cancellations, Omission Errors, Commission Errors, and Completion Time. The hypothesis for Similarity was supported with regard to Completion Time and Commission Errors. The hypothesis for Density was also supported for Completion Time.

Total Cancellations

The ANOVA performed on Total Cancellations was not significant between groups ($F(1,28) = 1.35, p = .254$) (see Figure 1). This indicates that the AD group did not make significantly more overall cancellations on a page than the control group.

Omission Errors

To determine whether omission performance differed between groups, an ANOVA was performed on Percent Omission Errors. Results of this ANOVA showed a non-significant trend for the main effect of group ($F(1,28) = 3.37, p = .08$) (see Table 9), with AD subjects making only somewhat more Omission Errors than controls (see Figure 2). This was unexpected, as it suggested that Omission Errors alone may not have discriminated performance between groups.

A significant main effect of Density ($F(2,476) = 35.23, p < .0001$) indicated that for both groups, performance deteriorated with increasing levels of density (see Table 9). To further assess the impact of Density, post-hoc analyses revealed that there were significant differences between Density levels 1 and 2 (qTukey = 5.5, df = 476, $p < .05$), levels 1 and 3 (qTukey = 8.2, df = 476, $p < .05$), and levels 2 and 3 (qTukey = 2.7, df = 476, $p < .05$) (see Figure 3). No interaction was found between Group x Density ($F(2,476) = 1.47, p = .23$), as the AD group made as many Omission Errors as the control group at all Density levels (see Figure 4).

A main effect of Similarity ($F(2,476) = 4.52, p < .01$) indicated that physical similarity influenced Omission Errors for both groups. Post-hoc tests revealed that errors

increased with physical similarity of the distractors (see Figure 5), with Similarity levels 1 and 3 significantly different (qTukey = 2.9, df = 476, p < .05), but with no significant differences between levels 1 and 2 (qTukey = 2.11, df = 476, p > .05, n.s.) or between levels 2 and 3 (qTukey = 0.80, df = 476, p > .05, n.s.). The Group x Similarity interaction was not significant ($F(2,476) = 2.11, p = .12$), as the performance of AD patients was always worse relative to controls.

While there was no main effect for Complexity ($F(1,476) = 0.04, p = .85$), the interaction of Complexity and Similarity was significant ($F(2,476) = 3.26, p = .04$). In order to elucidate the Complexity x Similarity interaction, post-hoc tests were performed. These post-hoc analyses revealed that at Complexity level 2, there was a significant difference between Similarity levels 1 and 2 (qTukey = 2.88, df = 476, p< .05), and levels 1 and 3 (qTukey = 3.75, df = 476, p< .05), but not between levels 2 and 3 (qTukey = 0.86, df = 476, p> .05) (see Figure 6). There were no significant differences between any levels of Similarity at Complexity level 3. Figure 6 shows that when only two different types of items were in the surround (Complexity = 2), the most similar distractors (Physical Similarity 3) resulted in the greatest number of Omission Errors (untransformed $M = 6\%$), followed by the next most similar distractors (Physical Similarity 2; untransformed $M = 5\%$). The presence of distractors that were physically very different from the target resulted in very few Omission Errors (untransformed $M = 2\%$). However, when three different types of distractors were in the surround (Complexity = 3), all types of distractors resulted in comparable Omission Errors (untransformed $M = 5\%, 5\%, 4\%$

for Similarity 3,2 and 1, respectively). This suggests that subjects become overloaded with different types of distractors on a page such that, regardless of how similar the distractors, subjects omit more targets. In contrast, when fewer types of items were in the surround, only the presence of very similar distractors caused Omission Errors. This interaction did not differ between groups.

Commission Errors

To determine whether commission performance differed between groups, an ANOVA was performed on Percent Commission Errors. Results of this ANOVA showed that the AD group performed more Commission Errors (untransformed $M = 2\%$) than the control group (untransformed $M = 0.2\%$) for all tests (see Figure 7), indicating a significant group effect ($F(1,28) = 12.73, p = .001$) (see Table 10).

Density had no effect on Percent Commission Errors ($F(2,476) = 0.38, p = .68$). In addition, no interaction was found between Group x Density ($F(2,476) = 0.19, p = .83$), as the AD group was consistently worse than the control group by the same amount at all Density levels.

There was a main effect of Similarity ($F(2,476) = 22.29, p < .0001$), with more Commission Errors as distractors were more physically similar. To compare the effects of Similarity level, post-hoc tests were done. These post-hoc tests revealed that there were significant differences between Physical Similarity levels 1 and 2 (qTukey = 4.5, df = 476, $p < .05$) and levels 1 and 3 (qTukey = 6.5, df = 476, $p < .05$), but not between levels 2 and 3 (Tukey = 1.98, df = 476, $p > .05$) (see Figure 8). The interaction between

Group and Similarity was also significant ($F(2,476) = 3.30$, $p = .04$) (see Figure 9). Tukey post-hocs tests revealed that in the AD group, there were significant differences between Similarity levels 1 and 2 (qTukey = 4.68, df = 476, $p < .05$), and levels 1 and 3 (qTukey = 6.26, df = 476, $p < .05$), but not between levels 2 and 3 (qTukey = 1.58, df = 476, $p > .05$). In the control group, significant differences existed only between Similarity levels 1 and 3 (qTukey = 2.95, df = 476, $p < .05$), and not between levels 1 and 2 (qTukey = 1.73, df = 476, $p > .05$) or levels 2 and 3 (qTukey = 1.21, df = 476, $p > .05$).

Density alone did not appear to influence the number of Commission Errors ($F(2,476) = 0\ .38$, $p = .68$). However, in order to determine whether Commission Errors were made when there was a combination of greater quantities of physically similar distractors in the surround, an ANOVA was performed. Density was found to significantly interact with Similarity ($F(4,476) = 2.65$, $p = .03$). To elucidate the Density and Similarity interaction, post-hoc tests were performed. Post-hocs revealed that at Density 1, significant differences were found between Physical Similarity levels 1 and 3 (qTukey = 4.92, df = 476, $p < .05$) and between levels 2 and 3 (qTukey = 3.64, df = 476, $p < .05$), but not between levels 1 and 2 (qTukey = 1.28, df = 476, $p > .05$, n.s.) (see Figure 13). At Density 2, no significant differences existed between any levels of Physical Similarity (qTukey = .16-2.63, df = 476, $p > .05$, n.s.). At Density 3, there were significant differences between Similarity levels 1 and 2 (qTukey = 3.94, df = 476, $p < .05$) and between levels 1 and 3 (qTukey = 3.89, df = 476, $p < .05$), but not between levels 2 and 3 (qTukey = .05, df = 476, $p > .05$, n.s.) (see Figure 10). Thus, when the

smallest number of items was presented on a page (Density 1), only the most similar distractors (Similarity 3) resulted in the greatest number of Commission Errors (untransformed $M = 4\%$). However, when the number of items on a page increased (Density 3), both the most similar (Similarity 3) and the next-most similar (Similarity 2) distractors resulted in comparable numbers of Commission Errors (untransformed $M = 2\%$). Since the interaction of Group x Density x Similarity was also not significant, this suggests that these effects of having larger numbers of similar distractors affects both groups equally, resulting in Commission Errors.

A main effect of Complexity ($F(1,476) = 10.58$, $p = .001$) indicated that performance was more difficult with more types of distractors, and the mean number of Commission Errors was more than three times greater at Complexity 3 (untransformed $M = 2\%$) than it was at Complexity 2 (untransformed $M = 0.6\%$; see Figure 11).

The interaction Complexity x Similarity ($F(2,476) = 4.48$, $p = .01$) was also significant. Post-hoc analyses revealed that at Complexity 2, there was a significant difference between Similarity levels 1 and 3 (qTukey = 3.94, df = 476, $p < .05$), but not between Similarity levels 1 and 2 (qTukey = 1.13, df = 476, $p > .05$, n.s.) or between Similarity levels 2 and 3 (qTukey = 2.81, df = 476, $p > .05$, n.s.) (see Figure 15). At Complexity 3 there were significant differences between Similarity levels 1 and 2 (qTukey = 5.28, df = 476, $p < .05$) and between Physical Similarity 1 and 3 (qTukey = 5.26, df = 476, $p < .05$), but not between Physical Similarity 2 and 3 (qTukey = .01, df =

476, p > .05, n.s.) (see Figure 12). The combined effect of a more complex field and increasingly similar stimuli appeared not to differ between groups.

Finally, the three-way interaction of Density x Complexity x Similarity ($F(4,476) = 3.70, p = .006$), and the four-way interaction of Density x Complexity x Similarity x Group ($F(4,476) = 3.05, p = .02$) were also significant. This indicates that the combination of increasing amounts of similar stimuli on a page and many different types of distractors similar to the target contribute to more Commission Errors in both groups, but disproportionately more Commission Errors in the AD group as compared to the control group.

Taken together, the two separate 4-way repeated-measures ANOVAs, performed on Percent Omission Errors and Percent Commission Errors, show that these error types differed between groups. Thus, these measures may be capturing different processes. Omission Errors, for example, may reflect poor search strategy. The main effect of Density without a Group x Density interaction suggests that Omission Errors were directly related to the number of stimuli present. The interaction of Complexity and Physical Similarity was also significant, demonstrating that when larger numbers of different items are in the surround, distractors of any similarity led to more Omission Errors. In contrast, AD patients make many more Commission Errors particularly when the stimuli are more similar. Both groups responded to Similarity, finding it more difficult to reject visually similar distractors. The further challenge of having similarity

with added types of different stimuli (Complexity and Physical Similarity) makes the rejection of distractors hardest.

Completion Time

For search Completion Time (see Figure 13), the AD group took longer to complete each test (untransformed M = 36 seconds) than the control group (untransformed M = 19 seconds) ($F(1,28) = 12.15$, $p = .002$).

A significant main effect of Density ($F(2,476) = 595.23$, $p < .0001$) indicated that for both groups, performance took longer with increasing levels of Density. Further post-hoc tests revealed that there were significant differences between Density levels 1 and 2 (qTukey = 22.86, df = 476, p < .05), levels 1 and 3 (qTukey = 33.81, df = 476, p < .05), and levels 2 and 3 (qTukey = 10.96, df = 476, p < .05) (see Figure 14). The interaction between Group x Density was also significant ($F(2,476) = 4.13$, $p = .02$), with AD subjects taking longer than controls to complete the task at all three levels of Density (see Table 11). Post hoc tests revealed that, within the AD group, there were significant differences between Density levels 1 and 2 (qTukey = 17.21, df = 476, p < .05), levels 1 and 3 (qTukey = 22.92, df = 476, p < .05), and levels 2 and 3 (qTukey = 5.71, df = 476, p < .05). Within the control group, there were also significant differences between Density levels 1 and 2 (qTukey = 15.11, df = 476, p < .05), levels 1 and 3 (qTukey = 24.89, df = 476, p < .05), and levels 2 and 3 (qTukey = 9.78, df = 476, p < .05) (see Figure 15). Therefore, the highest level of Density resulted in the longest Completion Time for both groups.

The main effect of Similarity ($F(2,476) = 37.02, p < .0001$) showed longer Completion Times as the distractors were more physically similar (see Figure 16). To assess the impact of Similarity, post-hoc tests were performed. These post-hoc tests revealed significant differences between Physical Similarity levels 1 and 2 (qTukey = 4.04, df = 476, p < .05), levels 1 and 3 (qTukey = 8.60, df = 476, p < .05), and levels 2 and 3 (Tukey = 4.56, df = 476, p < .05), with the highest level of Similarity taking the longest time. The interaction between Group and Similarity showed a trend toward significance ($F(2,476) = 2.85, p = .059$). Tukey post-hoc tests revealed that in the AD group, there were significant differences only between Similarity levels 1 and 3 (qTukey = 4.60, df = 476, p < .05), but not between levels 1 and 2 (qTukey = 2.83, df = 476, p > .05), or between levels 2 and 3 (qTukey = 1.78, df = 476, p > .05). In the control group, however, significant differences existed between Similarity levels 1 and 2 (qTukey = 2.89, df = 476, p < .05), levels 1 and 3 (qTukey = 7.56, df = 476, p <. 05) and levels 2 and 3 (qTukey = 4.67, df = 476, p < .05) (see Figure 17). The groups differed at all levels of Similarity, with AD subjects having the longest Completion Times at the highest level of Similarity.

There was also an effect of having physically similar distractors in the surround interacting with Density ($F(4,476) = 10.24, p < .0001$) (see Figure 18). Post-hocs revealed that at Density 1, significant differences were found between Similarity levels 1 and 3 (qTukey = 4.98, df = 476, p < .05) and between levels 2 and 3 (qTukey = 6.67, df = 476, p < .05), but not between levels 1 and 2 (qTukey = 1.68, df = 476, p > .05, n.s.). At

Density 2, there was a significant difference only between Similarity levels 1 and 3 (qTukey = 3.14, df = 476, $p < .05$). At Density 3, there were significant differences between Similarity levels 1 and 2 (qTukey = 6.11, df = 476, $p < .05$) and between levels 1 and 3 (qTukey = 6.77, df = 476, $p < .05$), but not between levels 2 and 3 (qTukey = .66, df = 476, $p > .05$, n.s.). In general, Completion Time increased both with increasing Density and with increasing Similarity.

There was no main effect of Complexity ($F(1,476) = 1.18$, $p = .279$), nor was the interaction Complexity x Similarity ($F(2,476) = 0.83$, $p = .44$) significant (see Table 11). Thus, the presence of more types of similar distractors in the field may not have caused an increase in Completion Time for either group.

Finally, the three-way interaction of Density x Complexity x Similarity ($F(4,476) = 2.99$, $p = .02$) was significant, but not by group. This indicates that the combination of increasing amounts of similar stimuli on a page and many different types of distractors similar to the target contribute to longer Completion Times in both groups.

Quadrant

In order to determine whether there was a bias to cancel more items in any one quadrant, separate 2-way repeated-measures ANOVAs (Group (2) and Quadrant (4)) were performed on transformed Percent Omission Errors and transformed Percent Commission Errors.

Omission Errors.

There was a trend toward a significant main effect of Quadrant ($F(3, 2159) = 2.17, p = .089$, trend) for the Omission Errors. However, there was no interaction between Group and Quadrant ($F(3, 2159) = 0.47, p = .70$).

Commission Errors.

There was no significant main effect of Quadrant ($F(3, 2159) = 1.08, p = .36$) for the Commission Errors, nor was there an interaction between Group and Quadrant ($F(3, 2159) = 0.58, p = .63$).

Since there was a trend toward an effect of Quadrant for Omission Errors, an additional analysis was done so as to elucidate whether a left or right visual field, or a top or bottom visual field bias was present. To do this, the top two quadrants were compared to the bottom two quadrants (comparing rows), and the left two quadrants were compared to the right two quadrants (comparing columns). Two separate 3-way repeated-measures ANOVAs (Group (2), Row (2), and Column (2)) were performed on transformed Percent Omission Errors and transformed Percent Commission Errors.

Omission Errors.

There was a significant row effect, with all subjects committing more Omission Errors on the top row ($F(1,476) = 5.25, p < .05$). Therefore, there was some top visual field bias for Omission Errors. This may be because the target stimulus remained in front of the subject throughout the experiment, underneath the cancellation tests, and therefore the proximity of the sample to the bottom of the page may have improved performance

somewhat on the bottom row compared to the top. There was no Column effect ($F(1,476) = 0.013$, $p > .05$), or Column x Row interaction.

Commission Errors.

There were no significant main effects of either Row ($F(1,476) = 0.023$, $p > .05$) or Column ($F(1,476) = 1.04$, $p > .05$) for the Commission Errors. This was expected, since the analysis for the effect of quadrant was not significant.

Order of Test Presentation

Omission Errors.

For the Omission Errors, the main effect of Order of Presentation was not significant ($F(17, 476) = 1.02$, $p = .43$) and the main effect of group was not significant ($F(1,28) = 3.37$, $p = .08$) (see Table 12). There was, however, a significant interaction between group and order of presentation ($F(17, 476) = 1.92$, $p = .01$), with the control group making significantly fewer Omission Errors than the AD group on tests presented later in the time sequence (see Figure 19). This may indicate that the controls improved their performance as a result of practice, or that the AD patients became fatigued.

Commission Errors.

With Commission Errors as the dependent variable, the effect of Order of Presentation was significant ($F(17,476) = 5.25$, $p < .0001$). The number of Commission Errors made by both groups decreased steadily over tests (see Figure 20). There was also a significant group effect ($F(1,28) = 12.73$, $p = .001$), since the AD group made an average of four times the Commission Errors that the controls made. However, the

interaction between Group and Order of Presentation (see Figure 21) was not significant ($F(17,476) = 0.51, p = .95$), since both groups showed a similar change in performance over the presentation of the tests (see Table 13).

Thus, order of test presentation had different effects on subject performance in both groups. For Omission Errors, the interaction between Group and Order of Presentation affected performance differently: Figure 19 shows that, toward the end of the sequence, the controls made fewer such errors. This is in contrast to the Commission Errors, for which significant main effects, combined with non-significant interactions, showed that both groups' commissions varied depending on the presentation (Figure 21 suggests that there were more Commission Errors earlier in the sequence), and the AD patients always had more errors. One interpretation is that, over time, both groups of subjects were able to learn to avoid making the mistakes necessary for Commission Errors, whereas the same was not true for Omission Errors.

Adjacency

Since the order of presentation of the tests was fixed (i.e., not randomized anew for each subject) an analysis of adjacency effects was performed to determine if any test consistently influenced the performance of the subsequent test. This analysis revealed no significant carryover effects.

Correlations with Neuropsychological Tests

AD Subjects

Omission Errors in the AD subjects appeared to be related to tests that tap attentional functions, while Commission Errors correlated primarily with dementia severity, and executive dysfunction. Completion Time correlated both with attentional tests and tests of disease severity.

Omission Errors.

Spearman correlations were conducted between Omission Errors across all experimental tests and groups of neuropsychological tests that were categorized by domain. The number of neuropsychological tests within a domain determined the number of tests in the correlation used to calculate the critical Rho (see Table 5).

Table 5: Critical Rho (ρ_I) Values for Each Correlational Analysis Following the Bonferroni Adjustment.

Number of tests in correlation	P-value	Critical Rho (ρ_I)
7	0.007	0.1633
11	0.0045	0.1722
12	0.0042	0.1739
16	0.003	0.1792
22	0.002	0.1850

Omission Errors appeared to be related mostly to attentional functions in general, and to a lesser extent to dementia severity, language, memory and executive dysfunction.

With regard to attentional functioning, Omission Errors were significantly correlated with both auditory and visual digit span (see Table 14). Specifically,

significant negative correlations were found between Omission Errors and digit span – forward (ρ_I = -.222; p = .0042), digit span - backward (ρ_I = -.389; p = .0042), and digit span - total (ρ_I = -.350; p = .0042), and visual span – backward (ρ_I= -.195; p = .0042) and visual span - total (ρ_I= -.219; p = .0042). These negative correlations indicated that AD subjects with decreased span also showed increased Omission Errors. The Dementia Rating Scale (DRS) Attention subtest was the only subtest of the DRS to be significantly correlated with Omission Errors (ρ_I = -.315; p = .007). Scores on this subtest were found to decrease as Omission Errors increased, indicating attentional deficits among those subjects with many Omission Errors. The Albert Line Cancellation, a test of selective attention, showed a positive correlation between number of errors on this cancellation test (ρ_I= .201; p = .0045) and Omission Errors, and a negative correlation between time to complete the test and Omission Errors (ρ_I = -.176; p = .0045). Finally, the digit symbol – coding test, another test of sustained attention, also correlated with Omission Errors (ρ_I = -.191; p = .0045), with lower scores on this test correlating with higher Omission Errors. Thus, there were a number of significant correlations between neuropsychological tests measuring attentional functioning and Omission Errors suggesting overall that reduced attentional functioning was associated with an increased probability of making Omission Errors.

There were few significant correlations between Omission Errors and those tests of cognitive functions that typically indicate poor performance in AD. For example, two main screening tools for AD include the Mini Mental Status Examination (MMSE) and

the total score on the DRS. Omission Errors were related to lower scores on the MMSE (ρ_I = -.212; p = .007), but the same was not also true for the DRS total. Some tests of language showed significant decreases as Omission Errors increased, such as semantic fluency (ρ_I = -.185; p = .0023), and the reading (ρ_I = -.323; p = .0023), writing (ρ_I = -.264; p = .0023), and comprehension (ρ_I = -.213; p = .0023) subtests of the Boston-Rochester Neuropsychological Screen (BRNS). However, of particular interest was the paucity of correlations with memory tests. A few tests of memory were correlated with Omission Errors. For example, scores on the Presidents subtest of the BRNS (ρ_I = -.229; p = .0023) decrease as Omission Errors increase, as does short delay free recall (ρ_I .219; p = .003) and recency (ρ_I = -.179; p = .003) on the California Verbal Learning Test - I (CVLT-I). Nevertheless, Omission Errors did not correlate with long delay free recall on the BRNS, nor the DRS Memory subtest. Finally, only one correlation was significant between Omission Errors and tests of "executive functioning." Difficulties with set-switching is supported by the positive correlation between Omission Errors and both Errors (ρ_I = .291; p = .0045 and time (ρ_I = .231; p = .0045) on the Trails-B test.

Thus, since a greater number of different attentional tests were correlated with Omission Errors, Omission Errors appear to be related mostly to overall attentional functioning. Several tests of dementia severity, language, memory and executive functioning also correlated with Omission Errors, indicating the relationship between Omission Errors and dysfunction in these cognitive domains.

Commission Errors.

To further explore why distractors were cancelled, Spearman correlations were used to investigate the relationship between Commission Errors of all the experimental tests and neuropsychological test scores. Commission Errors were found to correlate primarily with dementia severity, and executive dysfunction.

Correlations supported some difficulties with attention, and particularly visual attention and discrimination (see Table 14). For example, lower scores on the DRS Attention subtest were associated with increased Commission Errors (ρ_I = -.201; p = .007). The Attention subtest is made up of matching (discrimination), cancellation, and digit span tasks. Trails-A also showed a positive correlation with the amount of time taken to complete the task (ρ_I = .189; p = .0045) and the number of Commission Errors. This may reflect a slowed discrimination between numbers, or an inability to maintain visual attention over time. With regard to auditory digit span, neither digit span - forward nor digit span - backward showed a significant correlation. However, for visual span, visual span - backward (ρ_I = -.181; p = .0042), and visual span - total (ρ_I = -.178; p = .0042) were significantly correlated with increased Commission Errors. Visual span - forward did not show a significant correlation. As the experimental test was a visual task, this may indicate that some decrease in visual sustained attention may have contributed to Commission Errors, along with difficulties in visual discrimination.

It was found that as Commission Errors increased, there was a decrease in cognitive functioning (MMSE (ρ_I = -.182; p = .007); DRS total (ρ_I = -.210; p = .007)),

indicating that the more severely demented subjects made more Commission Errors. In addition to DRS Total decreasing, the DRS subscale of Initiation/Perseveration (ρ_I = -.212; p = .007) also decreased. However, the DRS Memory subscale was not significantly correlated with Commission Errors (ρ_I = -.137; n.s.).

Other correlations also showed decreased performance on those tests of cognitive function that typically suffer in AD. In terms of memory, scores on the Presidents subtest (ρ_I = -.269; p = .0023) of the BRNS decreased as Commission Errors increase. Significant correlations with language tests included scores on the Boston Naming Test (BNT) (ρ_I = -.291; p = .0045), as well as semantic fluency (ρ_I = -.208; p = .0023) and repetition (ρ_I = -.253; p = .0023) tests on the BRNS. Semantic fluency, in particular, is often found to be impaired in AD patients. The lowered score on the Initiation/Perseveration subscale of the DRS is also consistent with the inability to inhibit responses and to become stuck in set, which contributes to Commission Errors. Other correlations also support difficulties with disinhibition and perseveration. For example, positive correlations were found between Commission Errors and scores on the CVLT-I subtest of intrusions (ρ_I = .186; p = .003). Difficulty with set-switching is also supported by the positive correlation between Commission Errors and errors on the Trails-B test (ρ_I = .317; p = .0045).

Thus, in the AD patients, Omission Errors appeared to be related to tests that tap attentional functions, while Commission Errors correlated primarily with dementia

severity, and executive dysfunction. This suggests that distinct types of cognitive processes underlie each of these error types.

Completion time.

Completion Time in the AD patients appears to be related both to attentional functions and, to a lesser extent, to dementia severity

Completion Time was significantly correlated with a number of attentional tests (see Table 14). Specifically, significant negative correlations were found between Completion Time and digit span – forward (ρ_I = -.190; p = .0042), digit span - backward (ρ_I = -.208; p = .0042), and digit span - total (ρ_I = -.215; p = .0042), and visual span – forward (ρ_I = -.277; p = .0042), visual span – backward (ρ_I = -.328; p = .0042) and visual span - total (ρ_I = -.296; p = .0042). This indicated that AD subjects with increased Completion Time also showed decreased attentional span. The DRS Attention subtest was significantly correlated with Completion Time (ρ_I = -.268; p = .007). Scores on this subtest were found to decrease as Completion Time increased, indicating attentional deficits among those subjects who took longer to complete the tests. The digit symbol – coding test also correlated with Completion Time (ρ_I = -.459; p = .0045), with lower scores on this test correlating with higher Completion Time. Finally, Trails-A also showed a positive correlation between the number of errors on the test (ρ_I = .357; p = .0045) and Completion Time on the experimental tests. This may reflect an inability to maintain visual attention over time. Thus, there were a number of significant correlations between neuropsychological tests measuring attentional functioning and Completion

Time, suggesting overall that reduced attentional functioning was associated with increased Completion Time.

In order to determine if slowed Completion Time were a function of disease progression, Completion Time was correlated with neuropsychological tests of disease severity. There were some significant correlations between RT and those tests of severity. Longer Completion Time scores were related to lower scores on the MMSE (ρ_I = -.280; p = .007), and the DRS Memory subtest (ρ_I = -.210; p = .007). However, the same was not also true for the DRS total. Other tests that decline in AD also showed significant correlations with increased Completion Time, including memory tests such as the long delay free story recall (ρ_I = -.189; p = .0023) and delayed visual recognition (ρ_I = -.240; p = .0023) on the BRNS, and the recency effect on the CVLT-I (ρ_I = .322; p = .003). Nevertheless, Completion Time did not correlate with scores of free recall on the CVLT-I. Significant correlations with language tests included scores on the BNT (ρ_I = -.238; p = .0045), as well as phonemic fluency (ρ_I = -.331; p = .0023) and repetition (ρ_I = -.361; p = .0023) tests on the BRNS. Finally, the only correlation that was significant between Completion Time and executive functioning tests was a positive correlation on the CVLT-I subscore of intrusions (ρ_I = .232; p = .003), supporting difficulties with disinhibition. However, there was a negative correlation between Completion Time and errors on the Trails-B test (ρ_I = -.203; p = .0045). One hypothesis is that increased errors on this test might be the result of patients being careless, or alternatively, the result of poor set-shifting.

Thus, slower Completion Time in the AD patients appears to be related both to attentional functions and, to a lesser extent, to dementia severity, particularly with regard to memory.

Control Subjects

Compared to the AD subjects, there were very few significant correlations in the control group, and those that were significant did not follow a particular pattern as in the AD group.

Omission Errors.

In the control subjects, Omission Errors were not significantly correlated with any attentional tests (see Table 15). In terms of memory, only long delay cued recall on the CVLT-I (ρ_I = .217; p = .003) correlated significantly with Omission Errors. One language test, the FAS test of phonemic fluency, correlated with Omission Errors (ρ_I = .209; p = .0023). Finally, two correlations were significant between Omission Errors and tests of "executive functioning": false positives on the CVLT-I (ρ_I = -.266; p = .003) and time (ρ_I = -.186; p = .0045) on the Trails-B test.

Commission Errors.

The only neuropsychological test that was significantly correlated with Commission Errors for the controls was the BNT (ρ_I = -.206; p = .045), a language test.

Obviously, it is interesting that only one test correlated with Commission Errors (see Table 15). This may be because the controls showed so few Commission Errors.

Completion Time.

In the control group (see Table 15), Completion Time was negatively correlated with both the MMSE (ρ_I = -.290; p = .007) and the DRS total (ρ_I = -.187; p = .007), as well as the Initiation/Perseveration (ρ_I = -.165; p = .007) and the Conceptualization (ρ_I = -.236; p = .007) subscores of the DRS. Only one attentional test significantly correlated with Completion Time: digit span – forward (ρ_I = -.236; p = .0042). In terms of memory, short delay free recall on the CVLT-I (ρ_I = -.186; p = .003) correlated significantly with Completion Time, as did immediate story recognition (ρ_I = .239; p = .0023), immediate visual recall (ρ_I = -.277; p = .0023), and delayed story recall on the BRNS (ρ_I = -.186; p = .0023). One language test, the semantic fluency subtest of the BRNS, also correlated with Completion Time (ρ_I = -.225; p = .0023). Finally, four correlations were significant between Completion Time and tests of "executive functioning": false positives (ρ_I = .475; p = .003) and intrusion errors (ρ_I = -.183; p = .003) on the CVLT-I, and errors (ρ_I = .347; p = .0045) and time (ρ_I = .278; p = .0045) on the Trails-B test.

EXPERIMENT 2

Experiment 2 was done in order to determine the effect of varying the relative frequency of targets in the field on search. Thus, Target-to-Distractor Ratio and Density were manipulated in a visual search task. Five sets of Target-to-Distractor Ratio were determined, and the same three levels of Density that were used in Experiment 1 were used in this experiment.

Method

Participants

Experiment 2 had two groups: probable AD patients and healthy age-matched controls. The control subjects were the same as those used in Experiment 1. Experiment 2 used different patients, diagnosed with probable AD. The AD patients were screened and selected in the same manner as in Experiment 1. As in the former study, both groups of subjects were drawn from the same community, and equivalent mean age groups were achieved. Means and standard deviations (Experiment 2) for age, education, and MMSE, and gender and handedness distributions are listed in Table 6.

Table 6: Demographics of Subjects in Experiment 2.

	AD			Controls		
	range	mean	sd	range	mean	sd
age (yr)	67-88	77.2	5.91	64-86	74.91	6.11
education (yr)	8-20	14.31	3.51	8-20	14.71	3.01
MMSE	16-27	23.27	3.58	27-30	28.73	0.80
gender	12 females; 3 males			11 females; 4 males		
handedness	14 right; 1 left			14 right; 1 left		

One subject in Experiment 2 had three cancellation tests in which she cancelled everything on the page, indicating a failure to discriminate between stimuli. Further evaluation revealed that those tests in which she cancelled everything all occurred at the end of her presentation order. Therefore, this may have indicated that she was fatigued and failed to discriminate once she was so challenged. For these reasons, this subject was eliminated from the analyses.

Stimuli

Target and distractor stimuli used in Experiment 2 were selected from Experiment 1. The target was the same stimulus. The distractors chosen were all of Physical Similarity level 3 (most similar to the target), as this remained constant in Experiment 2.

Distribution of Stimuli

The cancellation tests in Experiment 2 had varying Target-to-Distractor Ratio (TDR) and Density. Varying the Density and the TDR resulted in the total number of targets and distractors per page as is shown in Table 7.

Table 7: Distribution of Targets and Distractors on Each Page as a Function of Target-to-Distractor Ratio and Density.

Level of Density	Number of Stimuli Per Page			TDR
	Total Stimuli	Targets	Distractors	
1	16	2	14	1:7
1	16	4	12	1:3
1	16	8	8	1:1
1	16	12	4	3:1
1	16	14	2	7:1
2	32	4	28	1:7
2	32	8	24	1:3
2	32	16	16	1:1
2	32	24	8	3:1
2	32	28	4	7:1
3	48	6	42	1:7
3	48	12	36	1:3
3	48	24	24	1:1
3	48	36	12	3:1
3	48	42	6	7:1

Stimuli Placement

The same procedure used in Experiment 1 to place targets and distractors on the experimental cancellation tests was repeated. Since the number of different types of

distractors on each test was kept constant at Complexity = 2 (two types of distractors), choosing which two of the three available distractor types to use for each test was determined randomly.

Procedure

Experiment 2 had 18 cancellation tests (15 experimental tests and 3 disjunctive, pop-out practice tests), which were administered to all subjects. As in Experiment 1, the order of the presentation of each experimental test was determined by quasi-random sequencing of the tests using a random number table.

Experimental cancellation tests and the neuropsychological tests were administered over a maximum of two sessions. Pre-tests, practice tests, and disjunctive control tests preceded the cancellation tests. Following the experimental tests, all subjects were administered the same post-tests as in Experiment 1, including those in which they were asked to rank order and judge the distance between stimuli.

Scoring and Analysis

Experimental cancellation tests and neuropsychological tests were scored in the same manner as in Experiment 1.

Percent Omission Errors, Percent Commission Errors, and Completion Time were recorded, and transformed as described in Experiment 1. Transformed data were used in the ANOVAs. The variable of total hits plus total commission errors (total cancellations) was computed and analyzed in a repeated-measures ANOVA. Completion Time was

divided by total cancellations to determine the rate of stimulus cancellation, and a repeated-measures ANOVA was performed.

To examine whether manipulations of Density and Target-to-Distractor Ratio differentially affected the groups, the transformed data (percent errors and completion time) and total cancellations were analyzed using separate 3-way repeated-measures ANOVAs, using the factors: Group (2), Target-to-Distractor Ratio (5), and Density (3). In order to determine whether there was a bias to cancel more items in any one quadrant, separate 2-way repeated-measures ANOVAs (Group (2) and Quadrant (4)) were performed on transformed percent Omission Errors and transformed percent Commission Errors. Since the order of presentation of the tests was the same for all subjects, separate 2-way repeated-measures ANOVAs (Group (2) and Order of Presentation (15)) were also performed on transformed percent Omission Errors and transformed percent Commission Errors. Autocorrelations were conducted to confirm that there were no adjacency effects (i.e., influence of one test on subsequent test or tests). An alpha level of .05 was used for all statistical tests.

To ascertain whether there was a relationship between experimental test performance and cognitive function, pair-wise correlations were conducted between the cancellation tests and the neuropsychological tests. Spearman's nonparametric rank correlation coefficients were calculated, and a Bonferroni adjustment was made to adjust the significance threshold in each analysis in proportion to the number of correlation coefficients compared.

Results

Overall, results for Experiment 2 indicated that the AD group had longer Completion Times than controls when Target-to-Distractor Ratio increased. The Time-per-Cancellation, however, was the same for both groups. AD subjects also made more Commission Errors as a function of the interaction between Target-to-Distractor Ratio and Density.

Analyses of Variance

Five separate 3-way repeated-measures ANOVAs were performed, one for each dependent variable: Total Cancellations, Omission Errors, Commission Errors, Completion Time, and Time Per Total Cancellations. The hypothesis for Target-to-Distractor Ratio was supported with regard to Completion Time and for the interaction between Target-to-Distractor Ratio and Density. Some aspects of the hypothesis for Density were also supported, such as the main effects.

Total Cancellations

The ANOVA performed on Total Cancellations was significant between groups ($F(1,27) = 7.19$, $p = .012$), indicating that the AD group made significantly more cancellations on a page ($M = 16.9$) than the control group ($M = 15.6$) over all tests (see Figure 22). The greater cancellations among AD patients, as will be seen in later analyses, were due to an increase in Commission Errors.

Omission Errors

To determine whether omission performance differed between groups, an ANOVA was performed on percent Omission Errors. Results of this ANOVA showed no main effect of group ($F(1,27) = 1.25, p = .27$) (see Table 16 and Figure 23), indicating that omission performance may not have discriminated the two groups.

A significant main effect of Density ($F(2,378) = 23.99, p < .0001$) indicated that, for both groups, performance deteriorated with increasing levels of Density (see Table 16 and Figure 24). To compare the effects of Density level, post-hoc tests were done. These post-hoc tests revealed that there were significant differences only between Density levels 1 and 2 (qTukey = 4.96, df = 378, p < .05) and levels 1 and 3 (qTukey = 6.67, df = 378, p < .05) (see Figure 24). No Group x Density interaction was found ($F(2,378) = 0.11, p = .90$), as the AD group was consistently worse than the control group at all levels of Density (see Figure 25).

A main effect of Target-to-Distractor Ratio ($F(4,378) = 4.01, p = .003$) indicated that this variable had an influence on Omission Errors for both groups (see Table 16). To further assess the impact of Target-to-Distractor Ratio, post-hoc comparisons revealed a significant difference only between Target-to-Distractor Ratio levels 1 (1:7) and 2 (1:3) (qTukey = 3.02, df = 378, p < .05) and levels 2 (1:3) and 5 (7:1) (qTukey = 3.22, df = 378, p < .05) (see Figure 26). Target-to-Distractor Ratio level 2 (1:3) resulted in the most Omission Errors. The Group x Target-to-Distractor Ratio interaction did not reach

significance ($F(4,378) = 1.02$, $p = .40$), as the pattern of performance of the AD patients was similar to that of controls (see Figure 27).

The interaction of Density x Target-to-Distractor Ratio ($F(8,378) = 3.68$, $p = .0004$) was significant (see Table 16). In order to elucidate the Density x Target-to-Distractor Ratio interaction, post-hoc tests were performed. These post-hoc analyses revealed that at Density level 3, there were significant differences between Target-to-Distractor Ratio levels 1 (1:7) and 2 (1:3) (qTukey = 4.40, df = 378, $p < .05$), Target-to-Distractor Ratio levels 2 (1:3) and 3 (1:1) (qTukey = 4.14, df = 378, $p < .05$), and Target-to-Distractor Ratio levels 2 (1:3) and 5 (7:1) (qTukey = 4.15, df = 378, $p < .05$) but not between any other two levels of Target-to-Distractor Ratio (see Figure 28). Thus, only when the largest quantity of stimuli was presented were the differences due to ratio apparent. Finally, the three-way interaction of Group x Density x Target-to-Distractor Ratio was not significant ($F(8,378) = 0.80$, $p = .60$), as both groups performed comparably.

Commission Errors

To determine whether commission performance differed between groups, an ANOVA was performed on Percent Commission Errors. Results of this ANOVA showed a significant group effect ($F(1,27) = 15.74$, $p = .0005$) (see Table 17), with the AD group making more Commission Errors (untransformed $M = 5.4\%$) than the control group (untransformed $M = 0.16\%$) for all tests (see Figure 29).

There was a significant main effect of Density on percent Commission Errors ($F(2,378) = 4.44, p = .012$) (see Table 17). To further assess the impact of Density, post-hoc tests revealed that there was a significant increase in Commission Errors between Density levels 2 and 3 (qTukey = 2.97, df = 378, $p < .05$), but not between Density levels 1 and 2 (qTukey = 1.71, df = 378, $p > .05$, n.s.) or levels 1 and 3 (qTukey = 1.26, df = 378, $p > .05$, n.s.) (see Figure 30). Commission Errors were highest at the highest level of Density. The interaction between Group x Density was not significant ($F(2,378) = 2.17, p = .12$), as the AD group showed a similar pattern to the control group of Commission Errors across Density (see Figure 31). However, it should also be noted that the control group made very few overall Commission Errors.

There was a trend toward a main effect of Target-to-Distractor Ratio ($F(4,378) = 2.21, p = .07$), with a smaller number of Commission Errors performed when there were few targets as compared to distractors (Target-to-Distractor Ratio levels 1 (1:7) and 2 (1:3)) (see Figure 32). The interaction between Group x Target-to-Distractor Ratio was not significant ($F(4,378) = 1.03, p = .39$), as both groups performed in a similar pattern across levels of ratio (see Table 19, Figure 33).

The interaction of Density x Target-to-Distractor Ratio ($F(8,378) = 10.97, p < .0001$) was significant (see Table 17). In order to elucidate the Density x Target-to-Distractor Ratio interaction, post-hoc tests were performed. These post-hoc analyses revealed that, when the smallest number of items was presented on a page (Density 1), the Target-to-Distractor Ratios that resulted in the greatest number of Commission Errors

were levels 3 (1:1) and 4 (3:1). When the number of items on a page increased (Density 2), the Target-to-Distractor Ratios that resulted in the greatest number of Commission Errors were levels 4 (3:1) and 5 (7:1). At the highest level of Density (level 3), Target-to-Distractor Ratio levels that resulted in the greatest number of Commission Errors were levels 3 (1:1) and 5 (7:1), with level 4 (3:1) having the least. This suggests that Density affects both the AD and control subjects enough so that there is an effect of ratio, resulting in Commission Errors. Specifically, at Density 1, significant differences were found between Target-to-Distractor Ratio levels 2 (1:3) and 3 (1:1) (qTukey = 5.55, df =378, $p < .05$), levels 2 (1:3) and 4 (3:1) (qTukey = 4.77, df =378, $p < .05$), levels 3 (1:1) and 5 (7:1) (qTukey = 5.19, df =378, $p < .05$) and between levels 4 (3:1) and 5 (7:1) (qTukey = 4.41, df = 378, $p < .05$) (see Figure 34). At Density 2, there were significant differences between Target-to-Distractor Ratio levels 3 (1:1) and 4 (3:1) (qTukey = 3.74, df = 378, $p < .05$) and levels 3 (1:1) and 5 (7:1) (qTukey = 3.64, df =378, $p < .05$). And at Density 3, there were significant differences between Target-to-Distractor Ratio levels 3 (1:1) and 4 (3:1) (qTukey = 3.63, df = 378 $p < .05$) and between levels 4 (3:1) and 5 (7:1) (qTukey = 4.73, df = 378, $p < .05$), but not between any other two levels. Further post hoc tests revealed that Target-to-Distractor Ratio level 3 (1:1) resulted in significantly greater Commission Errors at Density level 1(qTukey = 5.76, df = 378, $p < .05$) and level 3 (qTukey = 4.37, df =378, $p < .05$), compared to Density level 2. Target-to-Distractor Ratio level 4 (3:1) resulted in significantly more Commission Errors at Density level 1, compared to level 3 (qTukey = 4.25, df = 378, $p < .05$), and Target-to-

Distractor Ratio level 5 (7:1) showed significantly increased Commission Errors at Density level 3, compared to level 1 (qTukey = 4.89, df = 378, $p < .05$).

Finally, the three-way interaction of Group x Density x Target-to-Distractor Ratio ($F(8,376) = 6.45$, $p < .0001$) was also significant (see Table 17). This indicates that the combination of a greater number of targets relative to distractors along with an increased number of total items in the array (Target-to-Distractor Ratio x Density) caused an increase in Commission Errors for both groups, but disproportionately more Commission Errors in the AD group (see Figure 36) as compared to the control group (see Figure 35).

Completion time

For Completion Time, there was a significant group effect ($F(1,27) = 8.24$, $p = .008$). Specifically, the AD group took longer to complete each test (untransformed M = 31.4 seconds) than the control group (untransformed M = 22.7 seconds) (see Figure 37).

A significant main effect of Density ($F(2,378) = 915.70$, $p < .0001$) indicated that for both groups, performance took longer with increasing levels of Density (see Table 18). To assess further the impact of Density level, post-hoc tests revealed a significant increase in Completion Time between Density levels 1 and 2 (qTukey = 24.72, df = 378, $p < .05$), levels 1 and 3 (qTukey = 42.61, df = 378, $p < .05$), and levels 2 and 3 (qTukey = 17.89, df = 378, $p < .05$) (see Figure 38). Thus, both groups took longest to complete the task when the Density was highest (Group x Density interaction: $F(2,378) = 2.14$, $p = .12$ (see Figure 39)).

There was a main effect of Target-to-Distractor Ratio ($F(4,378) = 55.78$, $p < .0001$), with longer Completion Times when targets outnumbered distractors (see Figure 40): post hoc comparisons revealed that there were significant differences between Target-to-Distractor Ratio levels 1 (1:7) and 3 (1.1) (qTukey = 7.86, df = 378, p < .05), levels 1 (1:7) and 4 (3:1) (qTukey = 10.61, df = 378, p < .05), levels 1 (1:7) and 5 (7:1) (qTukey = 12.51, df = 378, p < .05), levels 2 (1:3) and 3 (1:1) (qTukey = 5.18, df = 378, p < .05), levels 2 (1:3) and 4 (3:1) (qTukey = 7.94, df = 378, p < .05), levels 2 (1:3) and 5 (7:1) (qTukey = 9.84, df = 378, p < .05), levels 3 (1:1) and 4 (3:1) (qTukey = 2.75, df = 378, p < .05), and levels 3 (1:1) and 5 (7:1) (qTukey = 4.66, df = 378, p < .05). The interaction between Group x Target-to-Distractor Ratio (see Figure 41) was also significant ($F(4,378) = 3.46$, $p = .009$). The AD group had significantly longer Completion Times at all levels of Target-to-Distractor Ratio. Furthermore, Completion Times became longer as Target-to-Distractor Ratio increased. To compare the effects of Target-to-Distractor Ratio level on Completion Time, post-hoc tests were done. These post-hoc tests revealed that in the AD group, there were significant differences between Target-to-Distractor Ratio levels 1 (1:7) and 3 (1:1) (qTukey = 4.22, df = 378, p < .05), levels 1 (1:7) and 4 (3:1) (qTukey = 5.82, df = 378, p < .05), levels 1 (1:7) and 5 (7:1) (qTukey = 6.37, df = 378, p < .05), levels 2 (1:3) and 4 (3:1) (qTukey = 4.26, df = 378, p < .05), and levels 2 (1:3) and 5 (7:1) (qTukey = 4.81, df = 378, p < .05). In the control group, significant differences existed between Target-to-Distractor Ratio levels 1 (1:7) and 3 (1:1) (qTukey = 6.85, df = 378, p < .05), levels 1 (1:7) and 4 (3:1) (qTukey = 9.13,

df = 378, p <. 05) and levels 1 (1:7) and 5 (7:1) (qTukey = 11.25, df = 378, p < .05). These results raise the question of whether the AD subjects are truly slower than the control subjects, or whether they are taking more time because they are making more Commission Errors.

There was also an effect of increasing Target-to-Distractor Ratio interacting with Density ($F(8,378) = 4.98, p < .0001$) (Figure 42). All Target-to-Distractor Ratio levels were significantly different between all levels of Density. Further test revealed that within Density 1, significant differences were found between Target-to-Distractor Ratio levels 1 (1:7) and 5 (7:1) (qTukey = 5.59, df = 378, p < .05), levels 2 (1:3) and 3 (1:1) (qTukey = 5.29, df = 378, p < .05), levels 2 (1:3) and 4 (3:1) (qTukey = 5.48, df = 378, p < .05), and levels 2 (1:3) and 5 (7:1) (qTukey = 7.77, df = 378, p < .05). At Density 2, there was a significant difference between Target-to-Distractor Ratio levels 1 (1:7) and 2 (1:3) (qTukey = 3.42, df = 378, p < .05), levels 1 (1:7) and 3 (1:1) (qTukey = 5.36, df = 378, p < .05), levels 1 (1:7) and 4 (3:1) (qTukey = 9.83, df = 378, p < .05), levels 1 (1:7) and 5 (7:1) (qTukey = 8.23, df = 378, p < .05), levels 2 (1:3) and 4 (3:1) (qTukey = 6.40, df = 378, p < .05) and levels 2 (1:3) and 5 (7:1) (qTukey = 4.81, df = 378, p < .05), and levels 3 (1:1) and 4 (3:1) (qTukey = 4.46, df = 378, p < .05). At Density 3, there were significant differences between Target-to-Distractor Ratio levels 1 (1:7) and 3 (1:1) (qTukey = 5.13, df = 378, p < .05), levels 1 (1:7) and 4 (3:1) (qTukey = 5.25, df = 378, p < .05), levels 1 (1:7) and 5 (7:1) (qTukey = 7.85, df = 378, p < .05), and levels 2 (1:3) and

5 (7:1) (qTukey = 4.47, df = 378, p < .05). In general, completion time increased both with increasing density and with increasing proportion of targets.

Finally, the three-way interaction of Group x Density x Target-to-Distractor Ratio ($F(8,378) = 0.49$, $p = .87$) was not significant.

Time Per Total Cancellations

An overall estimate of the rate of cancellation was determined by dividing Completion Time by the number of total cancellations per test. This variable was named "time per total cancellations" (see Table 19).

There was a trend toward a significant group effect for time per total cancellations ($F(1,27) = 3.37$, $p = .078$), as the AD group had a somewhat slower rate of cancellation (untransformed $M = 2.5$ seconds) than the control group (untransformed $M = 2.0$ seconds) (see Figure 43).

The time per total cancellations for both groups was not significantly different for Density ($F(2,378) = 2.26$, $p = .11$), as the rate of cancellation was similar at all levels of Density (see Figure 44). The interaction between Group x Density, however, showed a trend toward significance ($F(2,378) = 2.70$, $p = .068$) (see Figure 45), with the AD group taking significantly more time per total cancellations. Post hoc comparisons revealed significant differences between groups for Density 1 (qTukey = 5.44, df = 378, p < .05), Density 2 (qTukey = 6.27, df = 378, p < .05), and Density 3 (qTukey =3.11, df = 378, p < .05). This reflects the group difference, as the AD group is always slower at all levels of Density.

There was a main effect of Target-to-Distractor Ratio ($F(4,378) = 444.51, p < .0001$), with faster rates of cancellation as targets outnumbered distractors (see Figure 46). Additional tests revealed that there were significant differences between all Target-to-Distractor Ratio levels: between levels 1(1:7) and 2 (1:3) (qTukey = 11.71, df = 378, p < .05), levels 1 (1:7) and 3 (1:1) (qTukey = 25.76, df = 378, p < .05), levels 1(1:7) and 4 (3:1) (qTukey = 32.53, df = 378, p < .05), levels 1(1:7) and 5 (7:1) (qTukey = 35.36, df = 378, p < .05), levels 2 (1:3) and 3 (1:1) (qTukey = 14.05, df = 378, p < .05), levels 2 (1:3) and 4 (3:1) (qTukey = 20.82, df = 378, p < .05), levels 2 (1:3) and 5 (7:1) (qTukey = 23.65, df = 378, p < .05), levels 3 (1:1) and 4 (3:1) (qTukey = 6.77, df = 378, p < .05), levels 3 (1:1) and 5 (7:1) (qTukey = 9.60, df = 378, p < .05), and levels 4 (3:1) and 5 (7:1) (qTukey = 2.83, df = 378, p < .05). The interaction between Group and Target-to-Distractor Ratio, however, was not significant ($F(4,378) = 1.53, p = .19$), reflecting a similar pattern between groups at all levels of Target-to-Distractor Ratio (see Figure 47).

There was also a significant interaction between Target-to-Distractor Ratio and Density ($F(8,378) = 2.77, p = .005$) (see Figure 48). Post-hoc analyses clarified this interaction, revealing a very similar pattern of time per total cancellations between levels of Density. The only level of Target-to-Distractor Ratio that was significantly different between Densities was Target-to-Distractor Ratio level 1 (1:7): between Density levels 2 and 3 (qTukey = 21.70, df = 378, p < .05), and between Density levels 1 and 3 (qTukey = 22.95, df = 378, p < .05). Thus, the significance of the interaction is due to the significant effect of Target-to-Distractor Ratio on cancellation rate, and not an effect of

Density. Specifically, within Density 1, there were significant differences between all levels of Target-to-Distractor Ratio except between levels 4 (3:1) and 5 (7:1) (qTukey = 0.12, df = 378, p > .05, n.s.); within Density 2, there were significant differences between all levels of Target-to-Distractor Ratio except between levels 3 (1:1) and 4 (3:1) (qTukey = 3.04, df = 378, p > .05, n.s.), and within Density 3, there were significant differences between all levels of Target-to-Distractor Ratio except for between levels 4 (3:1) and 5 (7:1) (qTukey = 1.01, df = 392, p < .05). The three-way interaction of Group x Density x Target-to-Distractor Ratio ($F(8,378) = 0.94$, $p = .94$) was not significant (see Table 19).

Quadrant

Results of the quadrant analysis in both experiments showed no hemifield bias in the current experiments. This putatively means that the AD group did not show an overt neglect, or preference for one side of the visual field.

Omission Errors.

There was no significant effect of Quadrant on Omission Errors ($F(3, 1705) = 0.74$, $p = .53$), nor was there a Group x Quadrant interaction ($F(3, 1705) = 1.22$, $p = .30$).

Commission Errors.

There was no significant main effect of Quadrant on Commission Errors ($F(3, 1705) = 0.30$, $p = .82$), nor was there a Group x Quadrant interaction ($F(3, 1705) = 0.17$, $p = .92$).

Order of Test Presentation

Results showed that the ordinal position of the tests was not contributory to the error pattern in either the AD or control group, indicating that both groups were able to sustain attention throughout the task.

Omission Errors.

For the Omission Errors, the main effect of Order of Presentation was not significant ($F(14, 378)= 1.03, p = .42$) and the main effect of group was not significant ($F(1,27) = 1.25, p = .27$) (see Table 20 and Figures 49). The interaction between Group and Order of Presentation was also not significant ($F(14,378) = 1.26, p = .23$).

Commission Errors.

With Commission Errors as the dependent variable, the effect of Order of Presentation was significant ($F(14,378) = 1.91, p =.02$), with both groups making more Commission Errors earlier in the test presentation (see Table 21 and Figure 50). There was also a significant Group effect ($F(1,27) = 15.74, p = .0005$), since the AD group made an average of five times as many Commission Errors than the controls. However, the interaction between Group and Order of Presentation was not significant ($F(14,378) = 1.50, p = .11$), since both groups showed a similar change in performance over the presentation of the tests.

Adjacency

Since the order of test presentation was the same for all subjects, an autocorrelational analysis of adjacency effects was performed to determine if any test

consistently influenced the performance on the subsequent test. This analysis revealed no significant carryover effects.

Correlations with Neuropsychological Tests

AD Subjects

Omission Errors in the AD group appeared to be related to tests of attentional function and disease severity, while Commission Errors correlated primarily with tests of attention that drew on visual skills, as well as those memory tasks that demanded visual choice. Completion Time correlated only with tests of speed.

Omission Errors.

Spearman correlations were conducted between Omission Errors across all experimental tests and groups of neuropsychological tests that were categorized by domain. The number of neuropsychological tests within a domain determined the number of tests in the correlation used to calculate the critical Rho (see Table 8).

Table 8: Critical Rho (ρ_I) Values for Each Correlational Analysis Using the Bonferroni Adjustment.

Number of tests in correlation	P-value	Critical Rho (ρ_I)
7	0.007	0.1789
11	0.0045	0.1885
12	0.0042	0.1903
16	0.003	0.1962
22	0.002	0.2025

With regard to attentional function, Omission Errors were significantly correlated with auditory and visual digit span, including both forward and backward presentation.

Specifically, significant negative correlations were found between Omission Errors and digit span - backward (ρ_I = -.236; p = .0042) and digit span - total (ρ_I = -.192; p = .0042), and visual span – forward (ρ_I = -.293; p = .0042), visual span – backward (ρ_I = -.197; p = .0042) and visual span - total (ρ_I = -.273; p = .0042). This indicated that AD subjects with increased Omission Errors also showed decreased span. The DRS Attention subtest significantly correlated with Omission Errors (ρ_I = -.221; p = .007). Scores on this subtest were found to decrease as Omission Errors increased, indicating attentional deficits among those subjects with many Omission Errors. Omission Errors also correlated with the time to complete Trails-A (ρ_I = .279; p = .0045), but not with errors on this test, indicating relatively accurate search strategy. Finally, the digit symbol – coding test, another test of sustained attention, correlated with Omission Errors both in terms of errors (ρ_I = -.204; p = .0045) and time to completion (ρ_I = -.247; p = .0045). Thus, there were a number of significant correlations between neuropsychological tests measuring attentional functioning and Omission Errors suggesting, overall, that reduced attentional functioning was associated with an increased probability of making Omission Errors.

Omission Errors did relate to dementia severity, as indicated by correlations with the MMSE (ρ_I = -.214; p = .007) and the DRS total (ρ_I = -.186; p = .007). In both cases, lower scores on these tests (indicating more severe dementia) correlated with higher numbers of Omission Errors. However, there were no significant correlations between

Omission Errors and any tests in the language, memory, or executive functioning domains.

Thus, as in Experiment 1, Omission Errors appear to be related mostly to attentional functions and dementia severity, but not to tests of language, memory, or executive dysfunction.

Commission Errors.

Correlations of Commission Errors supported some difficulties with visual attention. For example, lower scores on the DRS Attention subtest were associated with increased Commission Errors (ρ_I = -.248; p = .007), and Trails-A showed a positive correlation between time taken to complete the task (ρ_I = .415; p = .0045) and the number of Commission Errors. With regard to auditory digit span, neither Digits Forward nor Digits Backward showed a significant correlation. However, for visual span, Visual Span Forward (ρ_I = -.291; p = .004) and Visual Span Total (ρ_I = -.243; p = .004) were significantly correlated with increased Commission Errors. That is, the significance of visual span as opposed to the auditory task may indicate that some decrease in visual sustained attention may be related to the Commission Errors. The Albert Line Cancellation showed a positive correlation between Commission Errors and both number of errors (ρ_I = .271; p = .0045) and time to completion (ρ_I = .222; p = .0045). The digit symbol – coding test also correlated with Commission Errors (ρ_I = -.403; p = .0045), with lower scores on this test correlating with higher Commission Errors. Finally, the DRS subscales of Construction (ρ_I = -.178; p = .007), and Conceptualization (ρ_I = -.253;

p = .007), half of which load on visual discrimination, did decrease with increasing Commission Errors. Thus, a relationship was seen between Commission Errors and in particular those tests which tap visual attention.

Unlike the Omission Errors, there were no significant correlations between Commission Errors and dementia severity (DRS Total (ρ_I = -.162; n.s.); MMSE (ρ_I = -.150; n.s.)). Other correlations showed decreased performance on those tests of cognitive function that typically suffer in AD. In terms of the memory domain, all auditory recall tests did not correlate with Commission Errors. Only visual recognition test scores on immediate (ρ_I = -.343; p = .0023) and delayed (ρ_I = -.279; p = .0023) story recognition subtests of the BRNS decreased as Commission Errors increased. Significant correlations with language tests included scores on the BNT (ρ_I = -.301; p = .0045), as well as semantic fluency (ρ_I = -.264; p = .0023), reading (ρ_I = -.271; p = .0023), comprehension (ρ_I = -.249; p = .0023), and repetition (ρ_I = -.216; p = .0023) tests on the BRNS.

Thus, in the AD patients, whereas Omission Errors appeared to be related mostly to attentional functions and dementia severity, Commission Errors correlated largely with those attention tasks that drew on visual skills, as well as those memory tasks that demanded visual choice.

Completion Time.

Completion time was not significantly correlated with most attentional tests. One exception was the positive correlation between Completion Time and time to completion

on the Albert line cancellation test (ρ_I = .350; p = .0045), reflecting the slower speed of the AD group.

Dementia severity and Completion Time were not significantly correlated (DRS Total (ρ_I = -.031; n.s.); MMSE (ρ_I = -.064; n.s.)). However, slowing was detected on the DRS Initiation/Perseveration subtest (ρ_I = -.202; p = .007), largely due to the fact that a number of tasks that make up this subtest are timed. While some memory tests showed significant correlations with increased Completion Time, including the presidents subtest (ρ_I = -.321; p = .0023) of the BRNS, short delay free recall (ρ_I = -.219; p = .003) and the recency effect on the CVLT-I (ρ_I = .232; p = .003), subjects' Completion Time did not correlate with scores of delayed recall on the CVLT-I. Significant correlations with language tests included scores on the BNT (ρ_I = -.280; p = .0045), and comprehension (ρ_I = -.228; p = .0023) on the BRNS. Finally, two executive functioning tests were correlated with Completion Time, including the negative correlation on intrusions on the CVLT-I (ρ_I = -.210; p = .0073, as well as time to completion on Trails-B (ρ_I = .352; p = .007).

Again, while Completion Time correlated with some tests of speed, it was not related to many of the tests of attention or dementia severity.

Control Subjects

The paucity of errors among control subjects resulted in few significant correlations with neuropsychological tests.

Omission Errors.

In the control subjects, Omission Errors were significantly correlated with visual span – backward (ρ_I = -.289; p = .004) and visual span – total (ρ_I = -.198; p = .004). However, on most other attentional tasks, virtually perfect performance as well as a low Omission rate result in a restricted range, thereby preventing meaningful correlations to emerge. Other significant correlations included long delay cued recall on the CVLT-I (ρ_I = .235; p = .003), the presidents subtest of the BR (ρ_I = -.204; p = .002), and false positives on the CVLT-I (ρ_I = -.241; p = .003).

Commission Errors.

The only tests significantly correlated with Commission Errors for the controls were Trails-A, time to completion (ρ_I = -.196; p = .0045), and the BNT (ρ_I = -.221; p = .0045), a language test. Again, few significant correlations are seen due to the fact that control subjects made very few Commission Errors and few errors on the neuropsychological tests.

Completion time.

In the control group, Completion Time was negatively correlated with both the MMSE (ρ_I = -.232; p = .007) and the DRS Conceptualization (ρ_I = -.207; p = .007) subscores of the DRS. That is, the longer the Completion Time, the lower the score. Completion Time did not significantly correlate with any attentional tests. In terms of memory, immediate story recognition (ρ_I =. -251; p = .0023), immediate visual recall (ρ_I = -.259; p = .0023), and delayed story recognition on the BRNS (ρ_I = -.216; p = .0023)

significantly correlated with Completion Time. Finally, three correlations were significant between Completion Time and tests of "executive functioning": false positives (ρ_I = .334; p = .003) on the CVLT-I, and errors (ρ_I = .277; p = .0045) and time (ρ_I = .189; p = .0045) on the Trails-B test.

DISCUSSION

The clinical criteria for the diagnosis of probable Alzheimer's disease (AD) do not include attentional deficits (McKhann et al., 1984). However, studies have documented that AD patients do show significant attentional impairment (Perry and Hodges, 1999; Parasuraman et al., 1992), and that these deficits emerge early in the course of the disease (Perry, Watson, and Hodges, 2000). Of the various subtypes of attention, selective attention appears to be highly vulnerable in AD (Foster, 2001; Parasuraman and Haxby, 1993; Perry and Hodges, 1999). Impairment in selective attention in AD may be due to any or all of the skills, such as search, detection, discrimination, and inhibition of distractors. Another explanation for selective attention deficits in AD is that multiple demands of a selective attention task reveal AD patients' sensitivity to increased perceptual load. Load has been defined as the amount of attentional effort or demand on available resources that a task requires (Kahneman and Treisman, 1984). The present investigation was designed to assess the effect of a systematic increase in load on visual selective attention in Alzheimer's disease. The two experiments of this investigation did so by varying the physical characteristics of a search task. Load was increased by manipulating similarity between targets and distractors

(Similarity), set size (Density), and the degree to which targets could stand out from their surround (Target-to-Distractor Ratio). Experiment 1 investigated the Physical Similarity and Density variables, and Experiment 2 investigated Density and the Target-to-Distractor Ratio variables. While Density has been documented as an adverse influence (i.e., Treisman, Sykes and Gelade, 1977), the role of Similarity and Target-to-Distractor Ratio has yet to be determined in a systematic fashion. The investigation was also unique in that it measured both the qualitative and the quantitative performance of AD patients as they are required to attend to increasingly demanding visual arrays.

Performance Abilities

Before any experimental effects of the conjunctive selective search task could be interpreted, the performance skills of the AD patients had to be determined. Specifically, it had to be determined that the AD subjects: were able to perform these tasks by demonstrating intact lower-level preattentional functioning, were not fatigued, were capable of discrimination mechanisms necessary to perform a selective search, or did not present with an overt visuospatial attentional bias. First, patients had to demonstrate their ability to perform a disjunctive (Treisman, 1964) search task, which would demonstrate abilities of preattentive analyses. Results showed that all patients were able to perform the disjunctive, pop-out task virtually without error. This finding corroborates previous studies in AD that demonstrated preserved preattentive processes in disjunctive searches compared to conjunctive searches (Parasuraman et al., 1995). Similarly, preserved

parallel processing was demonstrated by Nebes and Brady (1989), where colored stimuli were detected regardless of the size of the array.

A second area that had to be demonstrated was whether subjects' performance was due to fatigue. In terms of attention theory, fatigue addresses whether subjects can maintain sustained attention during a task and across the entire sequence of 18 (Experiment 1) or 15 (Experiment 2) tests, which lasted from approximately ten minutes to 25 minutes. Prior data on sustained attention suggests that AD patients do not show deficits in sustained attention initially, but do so only after prolonged periods (Brazzelli et al., 1994). Because Alzheimer's disease may put patients at risk for fatigue, the tests were counterbalanced by rotating the ordinal position of each test such that no one test was always in a particularly vulnerable position (i.e., at the end). Results of the current studies showed that the ordinal position of the tests was not contributory to the error pattern in either the AD or control group. Moreover, there were no carryover effects of any one test on its adjacent test, such that the higher error rate of one test did not influence the error rate of an adjacent test. In sum, the Alzheimer's patients were able to complete the full test sequence without fatigue. There was, however, one exception in Experiment 2, where a subject did fatigue, and indiscriminately cancelled all or virtually all of the stimuli on the page in the last five of 15 tests given. This subject's data, therefore, were excluded. The ability to perform all tests without fatigue was evidence of preserved sustained attention, a skill corroborated by previous experimental data (Nebes and Brady, 1993; Parasuraman and Nestor, 1993), as well as imaging data (Johannsen et

al., 1999) indicating equal brain activation during sustained tasks in AD subjects as in normal controls. The finding of preserved sustained attention was also consistent with neurobiological theories that point to an intact ascending reticular activating system in AD (Mesulam, 1981; Mesulam, 1998; Posner and Petersen, 1990). Lastly, the ability to perform the tasks with preserved sustained attention lends further validation to the completion time data that were used in the subsequent analyses.

There was concern whether the AD subjects could master the visual discrimination aspect of the task. It had to be established that all subjects were able to perform a simple discrimination task to demonstrate preserved visual perceptual skills. Results showed that all control and AD subjects achieved accurate pre- and post- 'same-different' discrimination tasks, where each stimulus was contrasted with only one or two other stimuli. Importantly, it was also necessary to determine that visual discrimination in a search context did not precipitate the AD subjects to falter and cancel all stimuli at random. Intact discrimination was demonstrated by comparing the two groups on overall cancellations. The results of Experiment 1 indicated that AD patients did not deteriorate, since there was no significant difference between AD and normal subjects in the overall number of stimuli cancelled. This indicates that since the number of overall cancellations did not appear to differ, the results would be a reflection of the effect of AD on the cancellation task. There were differences captured in Experiment 2, however, where a difference on all the cancellations was revealed: as will be discussed, this experiment was

more visually demanding and may have influenced the discrimination skills of the AD subjects.

Lastly, it was demonstrated that the spatial scanning skills of the AD patients was not biased. That is, they did not show a neglect, or a preference for one side of the visual field. A right hemifield bias, or left neglect, as seen in patients with focal right parietal damage, supports the hypothesis that the right hemisphere is dominant for important aspects of visuo-spatial search (Heilman, Valenstein and Watson, 1984). Usually AD patients do not show an overt visual field neglect, although some studies (Mendez et al., 1997; Foster et al., 1999; Ishiai et al., 2000) have demonstrated a right visual field bias. The concern for the studies was whether a hemifield bias would interact with, or even override the selective search skills. Results of the quadrant analysis in both experiments showed no hemifield bias in the current experiments. These data are at odds with the findings of Foster et al. (1999) who demonstrated in a selective attention task that items in the left periphery were most vulnerable and showed slower reaction time. Foster and colleagues' study differed, however, in several respects from the present study. One, it measured the reaction time of a single stimulus presentation, rather than requiring the subject to scan the entire visual field and respond to multiple target stimuli to generate a total completion time. A further difference was that the Foster et al. task measured reaction time in the context of the combination of a lateralized (i.e., items in the left or right visual field) and position (i.e., items in the center or extended in the periphery) stimulus presentation. It was only under the condition of left periphery that the right bias

was elicited. The failure to find a right hemifield bias in the current experiments may be due to the fact that, unlike in the Foster et al. study, subjects in the present studies were able to overtly search the field, and were given unlimited time to perform the search task. A bias may only emerge on more sensitive reaction time measures in covert orienting conditions.

In summary, these initial analyses established that the AD subjects in these experiments were representative of AD patients in general. They were able to perform preattentive tasks, to maintain sustained attention, to discriminate stimuli in non-search conditions, and to scan the entire visual field without a hemifield bias. These preserved areas of attentional function corroborate prior studies with AD patients demonstrating that not all areas of attention are equally affected (Perry and Hodges, 1999), and that sustained attention, preattentive functioning, and spatial attention are relatively spared in the early stages of the disease. Moreover, the primary visual processes required for discrimination are also intact.

Effects of Variable Manipulations

Similarity

Prior research has shown that the similarity between stimuli affects search. This was shown for young controls (Geldmacher, 1998; Hammar, 1998), healthy elderly (Scialfa, Esau, and Joffe, 1998; Scialfa and Harpur, 1994), and patients with neglect (Rapcsak et al., 1989). The current studies were designed in order to determine whether similarity per se would impair AD, or whether different levels of similarity, that represent

higher loads of visual discrimination, would affect AD patients differently than controls. Other studies have investigated the effects of similarity on AD patients. In a study comparing AD patients with young and elderly controls, Baddeley et al. (2001) found that AD subjects made more omission errors and had longer search time than controls when they had to search for the letter "Z" among angular letters (more similar) as opposed to curved letters (less similar). Amieva and colleagues (1999) showed that when subjects had to select geometric targets (squares with a line on top) from amidst similar distractors (squares with a line on another side), AD subjects made increased commission and omission errors compared to controls. Increased commissions among AD subjects were also found by Gainotti, Marra and Villa (2001), who presented targets (squares with two inside lines) among similar distractors (squares with variously oriented lines) to AD and multi-infarct dementia patients and controls. While these past studies, therefore, suggested that AD subjects were also vulnerable to similarity, the experimental paradigms did not manipulate similarity in a systematic fashion to determine if and at what point the visual load became too demanding. If the target detection aspect of search were impaired at all levels of similarity, this would suggest that visual discrimination, in the context of a search, is impaired. If, however, the detection of targets is only impaired when stimuli are very similar, then this would suggest that the demand of the higher load is the source of impairment for these patients. The current study tested three levels of increasing similarity measuring omissions errors, commission errors and search times for both healthy subjects and patients with AD.

The findings (Experiment 1) showed that both AD subjects and controls responded to the increase in similarity by making more commission errors. Importantly, though, the AD subjects made significantly more commission errors at the middle and highest level of similarity but did not differ from the controls at the lower, easier level of visual discrimination. This supports the hypothesis that increased similarity would impair AD subjects more than controls. Moreover, there was a trend showing that the groups differed in completion time, where AD subjects had their longest search time at the most difficult discrimination level. The longer search time in AD subjects was also predicted in the hypotheses. Omission errors (i.e., missed targets) were not significantly different between groups. The slower search time for the controls reflected the increased discrimination demands. But unlike the controls, the AD patients also made more commission errors and demonstrated as well an increase in search time. The fact that this error pattern was not seen throughout all levels of similarity, and only at the highest levels, supports the hypothesis that the load of the task, and not simply the discrimination demands, put the AD patients at the disadvantage. One hypothesis to explain these findings is that the slowed search time in the AD group may represent simply a slowed search speed, endorsing the concept that AD may represent an exacerbation of the aging process with its proposed generalized cognitive slowing (Salthouse and Somberg, 1982). Researchers in some studies (Parasuraman et al., 1995) have suggested that AD may be at the extreme end of a continuum of normal changes with aging; these authors found in that study that the reaction time of old-old subjects fell in between young-old and AD subjects

on an attention task of spatial cueing. Normal changes with aging include progressive cell loss in subcortical attentional regions (i.e., pulvinar, superior colliculi), seen in aging as well as AD (Braak and Braak, 1991), and are regions that may mediate the decrease in speed. The subcortical regions stand in contrast to parietal, extrastriate, and frontal region pathologic and metabolic changes, which are more specific to AD and not to aging.

The slowing hypothesis, however, only accounts for the speed of performance, and does not consider the error analysis. An alternative hypothesis was that AD subjects' response to the increased load was reflected in their errors as well as their speed. In other words, while the control group slowed their performance in order to avoid errors as Similarity increased, AD subjects took even longer to complete the task and made errors of commission in addition to the extra time. Two explanations for the increased commission errors could be posited. First, if perceptual discrimination were impaired, more commission errors would be seen. However, more omission errors may also have occurred, indicating a deficit in the ability to discriminate between stimuli to decide which are targets and which are distractors. Omission errors, however, appeared similar between groups: AD patients seemed capable of finding, identifying, and canceling the targets. Also, the prior findings showed that AD subjects were able to make the discriminations between stimuli outside the context of the search during the pre- and post-tests. Thus, it appears that discrimination, per se, was not impaired for the AD subjects.

An alternate explanation of the increase in commission errors was that as the load became too demanding, the AD subjects were unable to inhibit the distractors. At the highest levels of Similarity, the combination of searching, discriminating and avoiding distractors may have exceeded the available capacity of the AD patients. This results in being able to capture the targets, but slowing down and being unable to inhibit surrounding, non-relevant material. The concept of a general inhibitory breakdown has been posited in AD in situations of negative priming (Sullivan, Faust and Balota, 1995). Other of the aforementioned selective attention studies in AD also found greater commission errors in AD when targets and distractors were similar (Amieva et al., 1999; Gainotti et al., 2001). These authors attributed the commission errors to the fact that the target and distractors were physically similar. The current study contributed to these findings, but specified that similarity per se may not induce inhibitory errors, but rather that these errors are only in the context of the load-demanding situations of high similarity and search discriminations. It is the higher load that precipitated the failure of the inhibitory mechanism; the selective search mechanism, albeit faulty, can operate at lower load demands.

Inhibitory mechanisms are believed to be a component of executive functions. Therefore, correlational results of the present experiment could further support the notion that inhibition is defective in this group. The results found positive correlations between commission errors and tests measuring executive mechanisms. For example, tests of executive functioning including Trails-B and false positive recognition on the CVLT-I

scores correlated significantly with the commission errors. In addition, commission errors were also correlated with disease severity (i.e., MMSE and the DRS Total score). This suggests that an increase in inhibitory failure occurs with disease progression. These correlational results suggest that cognitive processes required to avoid canceling nontargets are a function of deficient executive functioning in AD, and occur more readily as disease severity increases.

Neurobiological evidence further supports the selective impairment in inhibition among AD subjects. The frontal system model of attention proposed by Stuss et al. (1995) predicts inhibitory difficulties as a result of damage to frontal areas. In particular, Stuss' model proposed that the dorsolateral frontal region subserves inhibition and he implicated the medial frontal area in the ability to prevent interference from the surround (Stuss et al., 2001). The perspective of Posner and Petersen (1990) also predicts vulnerability to interference due to damage to the anterior network (Posner, 1989), which is composed of the midline frontal region and the anterior cingulate gyrus. These frontal system areas are not functioning fully in AD, as confirmed by studies showing AD patients' reduced resting activation of the frontal lobe (Braak and Braak, 1991, 1995; Grady, et al., 1988; Grady et al., 1990; Montaldi et al., 1990). Thus, mechanisms of inhibiting and preventing interference have been linked to specific areas of the frontal system, which in turn have shown reduced activation in AD.

In sum, AD patients do respond to increased Similarity between stimuli. But they appear to do it differently than controls, with commission errors as well as increased

search time. It is posited that the increased errors result from a situation in which the demands of the task exceed the capacity available to the AD patients. Their deficits are not simply a failure to discriminate, but rather a failure to inhibit when the search and discrimination demands are at their highest.

Target-to-Distractor Ratio

In prior studies of selective attention in AD, density was confounded with the ratio of targets to distractors. The aim of the second experiment was to determine whether the relative ratio of targets to distractors influenced selective skills, while keeping density constant. The current cancellation study, one presenting multiple targets in a field, afforded that opportunity. In healthy young subjects, Geldmacher (1996) determined that lower target-to-distractor ratios precipitated more omission errors. Della Sala et al. (1992) showed that when subjects were required to cancel more targets (as target-to-distractor ratio increased), d' differences (hits minus false alarms) between AD and normal controls increased. These studies raised the question as to whether higher canceling demands varied as a function of the number of items to be searched, and/or as a function of the interference of the number of distractors in the surround. Cancellation of few targets surrounded by many distractors (low target-to-distractor ratio) requires search time to find the targets, followed by discrimination of targets from distractors, and the motor act of canceling. Cancellation of many targets interspersed with only a few distractors (high target-to-distractor ratio) necessitates active canceling of all the targets with discrimination and inhibition of the few distractors. Therefore, a shift in the ratio

may affect capacity demands differently, with each level of target-to-distractor ratio necessitating a different level of demand.

Experiment 2 manipulated target-to-distractor ratio over five levels, two levels where distractors outnumbered targets, two conditions where targets outnumbered distractors, and one level where targets and distractors were equal in number. Each level of ratio was presented at the three different levels of density. Again, omission errors, commission errors, and search time were collected for both subject groups.

Normal subjects responded to the levels of ratio by taking longer as the numbers of targets increased and distractors decreased, but they made virtually no errors. This showed that as they took the time, they were careful and performed the cancellation task without error. In contrast, the AD subjects did experience difficulty. They too increased their completion time at each level of ratio, but took significantly longer than the normals at every level, spending sometimes 50% longer to perform the search. While they identified the targets (no omission errors), they cancelled significantly more distractors than controls, albeit in an unsystematic pattern relative to the different levels of ratio and density. The concern was what this increase in completion time represented. One possibility was that the AD subjects searched more slowly, again supporting the concept of generalized cognitive slowing described in normal aging (Salthouse and Somberg, 1982). In this case, AD would again represent an exacerbation of the aging process.

A second explanation for the longer completion time among AD subjects is that the completion time reflects that the AD subjects cancelled more items (i.e., made more

commission errors) and needed more time to do so. In order to tease out the overall completion time, more data are needed to determine the reaction time of each cancellation. The use of an overall completion time in this study did not distinguish between time spent canceling the targets, time spent making commission errors, or time spent searching. Future studies may address this; for example, by using more accurate eye movement assessment that could help determine the AD subjects' search pattern and efficiency.

A third explanation focused on the rate of cancellation. The question was whether the cancellation rate contributed to the overall increase in completion time. That is, the time to cancel each stimulus may have varied, making the AD performance significantly longer. The rate may also have varied at each ratio level, since different ratio levels may have necessitated a different strategy to search, discriminate and carry out the motor task. The rate was determined by taking total completion time divided by the total number of cancellations performed, and an analysis compared this time for each group at each ratio level. This time-per-cancellation analysis showed that the rate of cancellation was similar for both normal controls and AD subjects. That is, both groups took the longest for the low target-to-distractor ratio and accelerated as the number of targets increased (which occurred as the target-to-distractor ratio increased). Thus, the findings showed that while there were similar patterns for cancellation rates in both groups, the AD subjects had significantly higher completion times and significantly higher commission errors. To interpret these findings, each cancellation was considered to be comprised of

search time, time to make perceptual discriminations, and time to motorically carry out the task. The differences of cancellation rate at different ratio levels may reflect a different distribution of each of these processes. A rapid cancellation rate, when many targets are in the field (high target-to-distractor ratios), may reflect that the search time was minimal, and the task became a rapid, repetitive motor task. In contrast, a slower cancellation rate, seen when few targets are present in the field (low target-to-distractor ratio), may be accounted for by either longer search times or slower motor skills, since discrimination per se was relatively intact.

The rate of cancellation, however, is only a gross estimate of performance and does not take into account that in instances where the commission errors were not high, the time spent on the tasks could be a reflection of inefficient search or other types of time-consuming distractions. The cancellation rate measure also cannot distinguish how the time-per-cancellation is subdivided, although it can be assumed to be comprised of search time and the time it takes to motorically cancel the stimulus items. Search time and motor slowing could differentially separate the two groups. Although dopamine reduction has been implicated in impairments of attention (e.g., spatial attention (Grujic et al., 1998) and alerting (Marrocco and Davidson, 1998)), early AD subjects have not been shown to be particularly vulnerable to motor slowing (Cummings and Benson, 1986) despite suspected decreases in dopamine (Barili, De Carolis, Zaccheo and Amenta, 1998). However, if motor function in AD and controls is thought to be roughly equivalent, the differences in time between the groups could be attributed to differences

in search time. This would indicate that a component of the higher completion time in AD was in part a function of an inefficient search.

Finally, an alternative explanation of the AD performance of increased completion time focuses on how variations in the ratio change the gestalt of the field. In other words, the change in ratio may alter the search task qualitatively, in that the switch from a few targets with many distractors to many targets with few distractors alters the figure-ground distinction of the perceptual field. This change in the perceptual demands of the task may have adversely affected the AD subjects' performance. Zohary and Hochstein (1989) proposed that healthy, young subjects make an initial figure-ground separation of the field in parallel, and then scan only the figure area in a serial fashion. This is consistent with the two-part analysis put forward by Treisman and Gelade (1980), in which subjects initially analyze the field in parallel, and then, in a conjunctive search, use serial processing to find the target. Treisman and Gelade (1980) demonstrated serial search by showing that completion time in a conjunctive search became longer with increasing overall set size. In contrast, Zohary and Hochstein (1989) stated that search time increased with increasing numbers of items in the figure alone. This idea supports the current findings of an increase in completion time as a function of increased items in the figure, or when the Target-to-Distractor Ratio increases (with progressively more targets in proportion to distractors). Since completion time was significantly longer in the AD subjects compared to controls, an additional explanation to the ones already proposed is that the AD subjects were more adversely affected by the increased

perceptual demands (or load) of the task as a result of the figure-ground reversal. This alteration in the gestalt of the field with changing ratio may have affected the AD subjects' ability to make decisions as to the relevance or non-relevance of the stimuli, and this decision-making difficulty could have contributed to the longer search time, as well as to errors of commission.

Density

Increasing Density, or the number of items in an array, was another means of increasing the load on the attentional resources. In both Experiments 1 and 2, Density was systematically increased over three levels in order to demonstrate that increased task demands affected visual selective skills in the AD patients. Density was also manipulated to determine how it interacted with Target-to-Distractor and Similarity parameters. Numerous previous studies have demonstrated an effect of increasing Density. Prior experiments have demonstrated longer search time with increased items on a page in young controls (Duncan and Humphreys, 1989; Treisman, Sykes and Gelade, 1977), healthy elderly (Geldmacher and Riedel, 1999; Posner and Presti, 1987), and patients with schizophrenia (Mori et al., 1996). Other studies have investigated the effects of density on AD patients, using different methods. Nebes and Brady (1989), using tachistoscopic presentation of increased array sizes in healthy young, old, and AD subjects, found increasing array size led to significantly slower response time in the AD subjects. Parasuraman and colleagues (Parasuraman et al., 1995; Greenwood et al., 1997) presented a conjunctive search task with two display sizes and cues of varying size. AD

subjects were the most affected, with the longest reaction times as display size and cue size increased. Foster, Behrmann, and Stuss (1999) showed completion time on target hits of AD patients on a conjunctive task increased disproportionately with increased array size; there was no such effect in the simple feature search. In a cancellation task, Foldi et al. (1992) varied the density of items in the field, as well as the number of different types of distractors in the surround (complexity). AD patients, age-matched controls and depressed patients showed more omissions as density increased, with a trend for the AD patients to be most sensitive to the density change. Moreover, it was the severity of illness that best predicted the sensitivity to the density. The present experiments sought to corroborate prior studies showing that AD patients respond more than controls to changes in density, with particular attention to how density interacted with changes in stimulus similarity and the ratio of targets to distractors.

Results of the current studies indicated that while both AD subjects and controls responded to Density, the groups did not differ in error rates. That is, as the number of items increased, AD patients and control subjects in Experiment 1 missed targets more frequently (i.e., made more omission errors) and had higher completion times. There was no effect of Density on commission errors. Importantly, AD patients differed from controls by taking significantly longer than controls at the highest level of Density, supporting some aspects of the hypothesis. While increasing density has been defined as increasing load (Duncan, 1980; Navon, 1989), it was only when there was the highest number of stimuli in the visual field that precipitated the differential search time between

groups. Caputo and Guerra (1998) indicated that those situations when distractors are in the close neighborhood of their targets are challenging to normal subjects, who become less accurate in identifying the presence of the target. Their close proximity condition simulates the high-density level of Experiment 1, the condition that required significantly more time in the AD subjects. Both groups responded similarly in response to increased Density, in that error rates (omission and commission errors) did not differentiate the two groups. That is, while neither group had an increase in commission errors with increased Density, both AD subjects and controls made omission errors as Density increased. These same errors of omission correlated with measures of attention (including the Digit Span, DRS Attention subtest, and errors on the Albert Line Cancellation Test) for both groups, implying that poorer target detection was associated with poorer attentional skills. Interestingly, omission errors had previously differentiated AD subjects from controls. Perry and Hodges (2000) found omission errors among AD subjects on the TEA Map Search Test, a study by Amieva et al. (1999) detected omission errors on a search task with similar distractors, and Della Sala et al. (1992) found omission errors with increased numbers of targets. Another study also showed increased omission errors among AD subjects compared to normals while varying density (Foldi et al., 1992). One reason for the difference between the current experiments and the Foldi et al. (1992) study is that the present experiments only required the search and cancellation of a single target, whereas the Foldi et al. (1992) study required patients to detect two different

targets in order to demonstrate group differences. When these authors used one target, group differences did not emerge.

An explanation for the significantly increased completion times among AD patients in Experiment 1 reflects the conjunctive, high-load condition of the search. According to Treisman and Gelade's Feature Integration Theory (1980), a conjunctive search uses more attentional capacity because the targets share features with the distractors, which have to be analyzed individually and then combined back into objects. Treisman and Gelade stated that conjunctive searches force items to be searched serially and attentively, which also increases the search time with increasing set size. Prior studies have shown disproportionate slowing on conjunctive tasks among AD subjects as compared to controls (Foster et al., 1999; Greenwood et al., 1997; Parasuraman et al., 1995), which is supported by studies of brain activity implicating posterior parietal activation during conjunctive tasks (Corbetta et al., 1995; Luck et al., 1993), areas especially vulnerable in the AD population (Haxby et al., 1985, 1986; Montaldi et al., 1990). While the higher load of a conjunctive search may have contributed to the increased search time with higher Density among AD subjects in Experiment 1, Similarity was also manipulated in this experiment. Duncan and Humphreys (1989) also showed an increased effect of set size, or density, in conjunctive tasks with similar targets and distractors. Thus, the contribution of the harder visual discriminations between similar stimuli together with the increase in Density in Experiment 1 may better explain the longer search time in AD.

The variation of Target-to-Distractor Ratio in Experiment 2 appears to have precipitated a slightly different type of effect on Density. Both groups again responded to the presence of increasing Density, as both controls and AD patients missed more targets as the set size increased and took longer to search the increasingly dense field. Remarkably, the AD group appeared not significantly different than controls in ability to master even some very high loads of visual input, and demonstrated relatively preserved search skills at higher Density. However, the density of the field did influence AD performance when the relative ratio between target and distractor changed, and AD subjects made significantly more commission errors. It was the concurrent variations of Density and Target-to-Distractor Ratio that resulted in sufficient load to impair the ability of the AD patients. And, again, the impairment was reflected in the inability to inhibit the irrelevant information.

Prior studies that demonstrated the effect of density on load (Treisman, Sykes and Gelade, 1977; Posner and Presti, 1987; Nebes and Brady, 1989) were done in experiments in which the density alone was the independent variable. In the present experiments, density was integrated with the perceptual demands of the physical similarity or the relative ratio of the targets to distractors. These latter two parameters may have overridden the density effect because they were visually more challenging in the context of a search. This suggests that prior information of the prominent effects of density should be adapted because of the results of this study. The negative effects of density can be obviated by making the task simpler. Unlike Foldi et al. (1992) who used

two targets, these experiments used only one target, and the group effect of density was curtailed. The concept of visual load in a search task can now be thought of as an interactive or even additive effect, when the source of the load can come from density alone or from a combination of density with other load-increasing variables such as similarity and target-to-distractor ratio.

In summary, AD patients could perform the task accurately in the current experiments when the load was low enough, and did not exceed the AD subjects' available capacity. But as the density increased, the AD subjects responded differently. As load increased to the highest level of Density, AD patients either slowed their search (Experiment 1) or, when the ratio varied, they were more susceptible to canceling distractors (Experiment 2). Past experiments are consistent with findings of increased search time in AD as a function of density (Foster et al., 1999; Greenwood et al., 1997; Nebes and Brady, 1989; Parasuraman et al., 1995). Unlike prior experiments that showed clear density effects, however, these new data suggest that other manipulations (e.g., Similarity and Target-to-Distractor Ratio) can diminish the influence of density alone.

Overall Summary

The results of these experiments support the notion that task load influences selective attention in AD. While AD patients can allocate attention in situations of lower load (i.e., disjunctive search), as load demands increase, they take longer to complete the task and are likely to make errors of commission. This suggests that when task demands exceed the capacity of the AD patients, their search mechanisms fail.

Increasing the Similarity between targets and distractors has been shown to increase load in AD patients (Amieva et al., 1999; Baddeley et al., 2001; Gainotti et al., 2001). But Experiment 1 demonstrated that the increase in commission errors and completion time occurred at the highest level of Similarity. Thus, while AD subjects are able to handle simple discriminations, as evidenced by accurate pre- and post-tests, the perceptual load of the task can increase beyond their available resources and force errors. Specifically, these errors are most often errors of commission, reflecting compromise in general inhibitory processes in AD (Sullivan, Faust and Balota, 1995). This inhibitory breakdown is further supported by neurobiological evidence of impaired inhibitory functioning with damage to frontal system areas (Stuss et al., 1995), as is seen in AD.

As the Target-to-Distractor Ratio load increased (Della Sala et al., 1992; Zohary and Hochstein, 1989), AD subjects were significantly slower than controls in performing a search task. This increased time may be partially explained by the increased commission errors among the AD group, but the time-per-cancellation analyses suggested that this might also be the result of a slower decision component of the search process, in which relevant stimuli are distinguished from irrelevant stimuli.

Increasing Density has been known to increase load, as evidenced by studies showing disproportionate increases in reaction time among AD patients as a result of increasing density (Foldi et al., 1992; Foster et al., 1999; Greenwood et al., 1997; Parasuraman et al., 1995). In Experiment 1, Density alone was related to an increased completion time among AD patients. This result supported Treisman and Gelade's

Feature Integration Theory (1980) by showing that the higher load of a conjunctive search took longer to complete with increasing set size, as a result of serial processing. The combined load resulting from the interaction between Density and Target-to-Distractor Ratio in Experiment 2 resulted in errors of commission. There still remains an explanation of why the AD subjects are much more sensitive to load.

Explanations for AD Subjects' Vulnerability

One theory is that AD patients are less able to draw on top-down, semantically based mechanisms that can be used in order to search more efficiently. They thus must rely on slower, less efficient bottom-up mechanisms. This creates a problem in situations where there is little bottom-up information (such as when there are minimal physical differences between stimuli), and control subjects then rely on top-down information in order to accurately search (Wolfe, 1994). Such a situation existed in Experiment 1, where the difference between the targets and the distractors became very small, resulting in little bottom-up activation. Thus, AD patients searched more slowly and less efficiently as a result of this increase in load.

Another possible explanation of the AD subjects' vulnerability to load posits a change in the capacity of AD patients. The overall size of the capacity in AD subjects may be reduced as a result of the disease, or the size of their capacity may be unchanged, but AD subjects may have reduced access to the capacity, or may make inefficient use of the capacity available. Inaccurate or slowed performance could be indicative of any of these possibilities. The effect of task load helps to explain the function of existing

capacity, since at lower levels of load, AD patients are able to perform the search task accurately. It is only at higher levels of load, or when a combination of tasks has to be performed simultaneously (Baddeley et al., 2001), that search mechanisms appear to break down and result in longer performance time and errors. The increased commission errors of AD subjects parallel results in normal aging literature, which showed that increasing the load by augmenting the surround, produced difficulty in suppressing distractors and increased errors of commission (Layton, 1975; Gilmore et al., 1985; Maylor and Lavie, 1998). While it is unclear whether the healthy controls in the present investigation performed "midway" between young and AD subjects such that the AD patients represent an exacerbation of normal aging, it is clear that the AD subjects are having difficulties above that of normal aging, since the controls in these experiments were age-matched.

Finally, there is the issue as to whether the present study actually detected attentional deficits in AD, or rather only deficits in executive functioning, especially given the pattern of commission errors among the AD subjects. To address this concern, it should be reiterated that the construct of attention has been linked to diverse areas of the brain, including frontal, parietal, and cingulate cortices, as well as subcortical regions, with each area subserving a different attentional process (Posner and Petersen, 1990; Mesulam, 1981). Attention and executive functions do overlap neuroanatomically in frontal regions, and certainly appear to interact cognitively in the mechanisms of inhibition and resistance to distraction. Thus, commission errors in particular can be

attributed to deficits in both selective attentional mechanisms as well as executive functioning. However, AD also affects the parietal lobes of the posterior network (Posner and Petersen, 1990), which has been linked to impairments in disengagement among AD patients (Parasuraman et al., 1992). Thus, given the combination of deficits seen and the different brain areas involved, the present task cannot differentiate between the contributions of attention and executive functioning, and thus both concepts have to be considered.

Theoretically, while Shallice (Shallice and Burgess, 1993) equated the Supervisory Attentional System with executive functioning, Baddeley (Baddeley et al., 2001) proposed that attention controlled executive processes through the Central Executive. In their study of AD patients, Perry and colleagues (Perry et al., 2000) stated that resisting interference and distraction was only one aspect of attentional control, and was affected early in AD. Thus, the relationship between attention and executive functioning remains unclear.

Other Considerations

Concern about Type II errors raised by several trends in the analyses warranted further consideration. A power analysis was not addressed in the planning stage of this study for two reasons. One was the already existing constraint of the limitation of patients who could meet inclusion criteria. The second reason was that a power analysis required established magnitudes of the effects in question, which could not be estimated in advance since experience with prior data using these stimuli was not available. Thus,

it remains possible that too few subjects could mean that the power is too low, and that Type II errors were made, indicating that small effects of the independent variable were undetected. Therefore, several important trends in the current study should be considered both ways - as if they were significant, as well as if they were non-significant - since they may have had an effect, albeit small, that might have been significant with more subjects. To support this speculation, an attempt was made, post hoc, to estimate the powers of four F-tests that were particularly germane to the conclusions of this study, but that did not reach the $p = .05$ criterion for significance. These were: in Experiment 1, the difference between AD and Control Groups in rate of Omission errors ($p = .08$; estimated power = 0.5); in Experiment 2, the effect of Target-to-Distractor Ratio on Commission errors ($p = .066$; estimated power = 0.7); in Experiment 2, the difference between AD and Control Groups on Time per Cancellation ($p = .078$; estimated power = 0.5); and in Experiment 2, the Group by Density interaction effect on Time per Cancellation ($p = .069$; estimated power = 0.6).

In the case of the Experiment 1 result, if the p value = .08 (Table 9, Figure 2) was said to be significant, and in fact showed a real (albeit small) effect, with AD subjects making more errors than controls, this might suggest that AD subjects were beginning to have difficulty detecting and identifying targets. This result would be consistent with prior literature, which found higher omission error rates among AD subjects as compared to controls (Amieva et al., 1999; Della Sala et al., 1992; Foldi et al., 1992; Perry and Hodges, 2000). This result would also be supported by correlations between omission

error rates and neuropsychological measures of attentional functioning, indicating that AD subjects' more limited attentional abilities were involved as well. If the p value was said to be significant, and in fact was not, this would indicate a Type I error, of rejecting the null hypothesis when it was in fact true. If, on the other hand, the p value was said to be not significant, and in fact was not, this would indicate that there was indeed no inter-group difference, and that the AD patients were as capable as controls of finding, identifying, and canceling the targets. The interpretation of this was offered in the discussion (page 120). Finally, if the p value was said to be not significant, but in fact showed a real (albeit small) effect, this would result in a Type II error, of failing to reject the null hypothesis when it was false. Indeed, the power of 0.5 estimated for this particular test means that there was a 50% chance of making a Type II error and of missing an effect. In the interpretation of the results from Experiment 1, it was concluded that AD patients only had longer completion times and more commission errors than controls. Omission error rates were said not to differ. If AD patients did show impairments in all three dependent variables, then this interpretation would be insufficient. In the case of additional significant omission errors, AD patients might also be showing deficits of discrimination and detection, as well as of inhibition and speed.

Similarly, in Experiment 2, the p value = .066 (Table 17, Figure 32) could be said to be significant, and in fact show a real, although small, effect of Target-to-Distractor Ratio on Commission errors, with more errors being made at higher levels of Target-to-Distractor Ratio. One explanation for this might be that when there are many targets

interspersed with only a few distractors (high Target-to-Distractor Ratio), subjects may perceive this as a reversal of the low Target-to-Distractor Ratio condition, and reverse the figure-ground gestalt, resulting in more errors. If the p value was said to be significant, and in fact was not, this would indicate a Type I error. In this case, the five levels of Target-to-Distractor Ratio would actually not differ, and the figure-ground interpretation for the errors would be false. On the other hand, if the p value was said to be not significant, and in fact was not, this would indicate that there was indeed no difference between Target-to-Distractor Ratio levels, and that the proportion of targets relative to distractors on a page had no effect on the tendency to mistakenly cancel nontargets. Lastly, if the p value was said to be not significant, but in fact showed a small effect, this would result in a Type II error. The power of 0.7 estimated for this particular test means that there was a 30% chance of making a Type II error and of missing an effect. The interpretation of the effect could be that Target-to-Distractor Ratios of 1:1 and higher are perceived differently than Target-to-Distractor Ratios less than 1:1, resulting in more commission errors.

In the case of the difference between Groups on Time per Cancellation in Experiment 2, if the p value of .078 (Table 19, Figure 43) was deemed significant, and actually was, then the interpretation could be that the rate of cancellation was slower for the AD subjects than the controls because the AD subjects are simply slower overall, supporting the cognitive slowing hypothesis (Salthouse and Somberg, 1982). This slower rate of cancellation could then account for the AD subjects' longer completion time.

However, if the p value was said to be significant, and actually was not, this would indicate a Type I error. In this case, there would be no difference between groups. In contrast, if the p value was said to be not significant, and in fact was not, this would indicate that the rate of cancellation was similar for both groups. Some other factor (i.e., inefficient search) would then have to account for the longer completion time among the AD subjects. Finally, if the p value was said to be not significant, but in fact did show a small effect, this would again result in a Type II error. In this case, the power of 0.5 estimated for this test would mean that there was a 50% chance of making a Type II error and of missing an effect.

Lastly, in the case of the Group by Density interaction measured by Time per Cancellation in Experiment 2, if the p value = .069 (Table 19) was said to be significant, and in fact showed a real (albeit small) effect, this might suggest that the AD group's cancellation rate was differentially affected by Density level. A significant interaction would prompt further investigation into where the effect was originating, either by post-hoc analysis or by observing a graph of the results. By looking at Figure 45, it could be speculated that the AD group is taking less time for each cancellation at the highest Density level. If the p value was said to be significant, and in fact was not, this would indicate a Type I error. If, on the other hand, the p value was said to be not significant, and in fact was not, this would indicate that there really was no effect of a Group by Density interaction on Time Per Cancellation, and that the overall rate of cancellation was unaffected by the number of items on a page. Finally, if the p value was said to be

not significant, but in fact did show an effect, this would again result in a Type II error, of failing to reject the null hypothesis when it was false. Indeed, the power of 0.6 estimated for this particular test means that there was a 40% chance of making a Type II error and of missing an effect.

Thus, the interpretation of those instances of significance values that did not reach $p < .05$ values require some consideration of the chances that Type II errors were made. In the future, modifications of the current study could increase the probability of seeing an actual effect. For example, more subjects could be added to increase the power. It was estimated that to raise the power of these tests to a level of 0.8 or greater would have required increasing the group sizes from 15 subjects each to about 30-35 subjects each. Alternatively, the tests could be made more difficult in order to see a larger effect.

The effect of disease severity also needs to be examined. Dementia severity is a score, as measured by the Mini-Mental Status Exam (MMSE; Folstein et al., 1975), ranging from 0-30 points. In order to determine whether level of dementia severity may have impacted performance in the present study, correlations were conducted between scores on the MMSE and performance on the cancellation tests. Omission and commission error rates were analyzed separately. This resulted in significant negative correlations among the AD subjects in Experiment 1 (Table 14), indicating that lower MMSE scores were associated with greater omission and commission errors. In Experiment 2 (Table 22), only omission errors showed this significant negative correlation. In other words, the more demented patients generally made more errors on

these cancellation tests than less demented patients. However, while subjects had to meet neuropsychological criteria of MMSE Score < 26 (Monsch et al., 1993) and/or Dementia Rating Scale (DRS) < 130 in order to be considered patients with probable AD and participate in the study, there was a range of MMSE scores within the patient groups. For example, in Experiment 1, the AD group's MMSE scores ranged from 12-26, and in Experiment 2, from 16-27. These MMSE scores encompass the dementia severity subdivisions used by the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) of mild (MMSE score ≥24), moderate (19-23), and severe (10-18) AD (Welsh et al., 1991). According to these subdivisions, in Experiment 1, 4 subjects would be considered mild, 8 were moderate, and 3 were severe. In Experiment 2, 8 were mild, 5 were moderate, and 1 was severe. Thus, while it appears that disease severity influenced attentional performance, future research calls for a replication of the present study using different groups of patients at different stages of the disease, in order to provide a more finely graded estimate of the rate of attentional decline in AD.

A consideration of disease severity could also be used to clarify the role of attention in the progression of the disease. For example, if only very mild patients were included in the study and still differed from controls, this would indicate that the test was very sensitive to even small changes in cognitive function. This could also be used to support the proposal that attentional changes occur very early on in the course of AD (Perry, Watson and Hodges, 2000).

Applications

In the everyday life of an AD patient, deficits in selective attention skills disturb the ability to perform many tasks. For example, the multifaceted task of driving is susceptible. Or, the inability to inhibit distraction may manifest itself in the AD patient's choosing the wrong, but similar-looking, medication from the cabinet. These types of errors can have very significant consequences. Thus, we know from the results of the present study that, in order to optimize performance of such tasks in AD patients, load should be reduced as much as possible. For example, knowing about vulnerability to set size, AD patients can be asked to select from a smaller array of choices. Given AD patients' deficits in inhibiting similar-looking items, caregivers should limit easily confusing objects. And knowing about AD patients' inefficiency in searching for relevant items that don't stand out from the environment, adaptations have to be made by caregivers to make these relevant items more salient. These adaptations would help reduce confusion and mistakes in AD patients, as well as subjective feelings of being overwhelmed.

TABLES

Table 9: Experiment 1 - ANOVA Source Table With Omission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	1.43	1	1.43	3.37	.08, trend
Error	11.89	28	.42		
Within Subjects					
Density	2.99	2	1.50	35.23	<.0001*
Similarity	.38	2	.19	4.52	<.01*
Complexity	.002	1	.002	.04	.85, n.s.
Group x Density	.12	2	.06	1.47	.23, n.s.
Group x Similarity	.18	2	.09	2.11	.12, n.s.
Group x Complexity	.003	1	.003	.06	.80, n.s.
Similarity x Density	.06	4	.02	.38	.82, n.s.
Similarity x Complexity	.28	2	.14	3.26	.04*
Density x Complexity	.005	2	.002	.06	.94, n.s.
Group x D x C	.09	2	.05	1.07	.35, n.s.
Group x D x S	.17	4	.04	.99	.41, n.s.
Group x C x S	.08	2	.04	.91	.40, n.s.
D x C x S	.04	4	.01	.26	.91, n.s.
Group x D x C x S	.18	4	.05	1.07	.37, n.s.
Error	20.21	476	.04		

*indicates significance, $p<0.05$ or less

Table 10: Experiment 1 - ANOVA Source Table With Commission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	1.65	1	1.65	12.73	.001*
Error	3.62	28	.13		
Within Subjects					
Density	.02	2	.01	.38	.68, n.s.
Similarity	1.13	2	.57	22.23	<.0001*
Complexity	.27	1	.27	10.58	.001*
Group x Density	.01	2	.005	.19	.83, n.s.
Group x Similarity	.17	2	.08	3.30	.04*
Group x Complexity	.02	1	.02	.72	.40, n.s.
Similarity x Density	.27	4	.07	2.66	.03*
Similarity x Complexity	.23	2	.11	4.48	.01*
Density x Complexity	.02	2	.01	.31	.74, n.s.
Group x D x C	.02	2	.01	.32	.73, n.s.
Group x D x S	.03	4	.01	.28	.89, n.s.
Group x C x S	.15	2	.07	2.86	.06, trend
D x C x S	.38	4	.09	3.70	.006*
Group x D x C x S	.31	4	.08	3.05	.017*
Error	12.11	476	.03		

*indicates significance, $p<0.05$ or less

Table 11: Experiment 1 - ANOVA Source Table With Completion time as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	57.67	1	57.67	12.15	.002*
Error	132.87	28	4.75		
Within Subjects					
Density	86.97	2	43.49	595.23	<.0001*
Similarity	5.41	2	2.70	37.02	<.0001*
Complexity	.09	1	.09	1.18	.28, n.s.
Group x Density	.60	2	.30	4.13	.02*
Group x Similarity	.42	2	.21	2.85	.059, trend
Group x Complexity	.02	1	.02	.30	.58, n.s.
Similarity x Density	2.99	4	.75	10.24	<.0001*
Similarity x Complexity	.12	2	.06	.83	.44, n.s.
Density x Complexity	.17	2	.09	1.18	.31, n.s.
Group x D x C	.04	2	.02	.23	.75, n.s.
Group x D x S	.22	4	.05	.74	.57, n.s.
Group x C x S	.13	2	.07	.89	.41, n.s.
D x C x S	.87	4	.22	2.99	.02*
Group x D x C x S	.44	4	.11	1.50	.20, n.s.
Error	34.76	476	.07		

*indicates significance, $p<0.05$ or less

Table 12: Experiment 1 - ANOVA Source Table for Order of Presentation With Omission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	1.43	1	1.43	3.37	.08, n.s.
Error	11.89	28	.42		
Within Subjects					
Order of Presentation	.82	17	.05	1.02	.43, n.s.
Group x Order	1.54	17	.09	1.92	.01*
Error	22.44	476	.05		

Table 13: Experiment 1 - ANOVA Source Table for Order of Presentation With Commission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	1.65	1	1.65	12.73	.001*
Error	3.62	28	.12		
Within Subjects					
Order of Presentation	2.35	17	.14	5.25	<.0001*
Group x Order	.23	17	.01	.51	.95, n.s.
Error	12.54	476	.03		

*indicates significance, $p<0.05$ or less

Table 14: Experiment 1 – Spearman Correlations for Omissions, Commissions, and Completion Time with Select Neuropsychological Tests: Alzheimer's Disease

Cognitive Function Assessed	Neuropsychological Test	Correlation with Omissions (Critical Rho Value)	Correlation with Commissions (Critical Rho Value)	Correlation with Completion Time (Critical Rho Value)
Severity Screening	MMSE	-0.212*	-0.182*	-0.280*
	DRS-Total	-0.106	-0.210*	-0.094
Attentional Functioning	DRS-Attention	-0.315*	-0.201*	-0.268*
	Trails A – Errors	0.124	-0.097	0.357*
	Trails A – Time	0.149	0.189*	0.477*
	Digit Coding Percentile	-0.191*	0.009	-0.415*
	Line Cancellation – Errors	0.201*	-0.118	0.145
	Line Cancellation – Time	0.176	0.049	0.494*
	Digit Span - Forward	-0.222*	-0.051	-0.190*
	Digit Span - Backward	-0.389*	-0.119	-0.208*
	Digit Span - Total	-0.350*	-0.109	-0.215*
	Visual Span - Forward	-0.112	-0.162	-0.277*
	Visual Span - Backward	-0.195*	-0.181*	-0.328*
	Visual Span – Total	-0.219*	-0.178*	-0.296*

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Memory Functioning	DRS-Memory	-0.106	-0.137	-0.210*
	CVLT-I – Short Delay Free Recall	0.219*	-0.020	-0.162
	CVLT-I – Long Delay Free Recall	-0.063	-0.030	-0.115
	CVLT-I – Recency	0.179*	0.117	0.322*
	BRNS – Immediate Visual Recall	-0.249*	-0.108	0.001
	BRNS – Immediate Story Recognition	-0.073	-0.086	0.178
	BRNS – Long Delay Free Story Recall	0.036	-0.159	-0.189*
	BRNS – Delayed Visual Recognition	0.253*	-0.211*	-0.240*
	BRNS – Presidents	-0.229*	-0.269*	-0.018
Executive Functioning	DRS-Initiation/Perseveration	-0.115	-0.212*	-0.046
	DRS-Conceptualization	0.085	0.065	-0.084
	CVLT-I – Intrusions	0.078	0.186*	0.232*
	CVLT-I – False Positives	0.150	0.143	-0.043
	Trails B – Errors	0.291*	0.317*	-0.203*
	Trails B – Time	0.231*	0.144	0.049
Language Functioning	BNT	-0.155	-0.291*	-0.238*
	Semantic Fluency	-0.185*	-0.208*	-0.014
	Phonemic Fluency (FAS)	-0.014	0.031	-0.331*
	BRNS - Reading	-0.323*	-0.023	-0.029
	BRNS - Writing	-0.264*	0.065	0.162
	BRNS - Comprehension	-0.213*	0.016	0.149
	BRNS - Repetition	-0.151	-0.253	-0.361*

*indicates significance, $p<0.05$ or less

Table 15: Experiment 1 – Spearman Correlations for Omissions, Commission, and Completion Time with Select Neuropsychological Tests – Controls.

Cognitive Function Assessed	Neuropsychological Test	Correlation with Omissions (Critical Rho Value)	Correlation with Commissions (Critical Rho Value)	Correlation with Completion Time (Critical Rho Value)
Severity Screening	MMSE	0.044	-0.140	-0.290*
	DRS-Total	0.065	-0.040	-0.187*
Attentional Functioning	DRS-Attention	-0.124	0.104	0.096
	Trails A – Errors	0.124	-0.104	-0.096
	Trails A – Time	-0.005	0.153	0.204*
	Digit Coding Percentile	-0.114	0.009	-0.080
	Line Cancellation – Errors	0.000	-0.118	0.000
	Line Cancellation – Time	-0.003	0.049	0.155
	Digit Span - Forward	0.051	-0.050	-0.236*
	Digit Span - Backward	0.086	-0.038	-0.066
	Digit Span - Total	0.093	-0.023	-0.154
	Visual Span - Forward	-0.005	-0.154	-0.121
	Visual Span - Backward	-0.169	-0.148	0.012
	Visual Span – Total	-0.080	-0.153	-0.052

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Memory Functioning	DRS-Memory	0.053	0.041	-0.155
	CVLT-I – Short Delay Free Recall	0.115	0.030	-0.186*
	CVLT-I – Long Delay Free Recall	0.021	-0.032	0.014
	CVLT-I – Recency	0.040	0.115	-0.137
	BRNS – Immediate Visual Recall	-0.115	-0.140	-0.277*
	BRNS – Immediate Story Recognition	0.026	-0.061	-0.239*
	BRNS – Long Delay Free Story Recall	-0.008	-0.152	-0.186*
	BRNS – Delayed Visual Recognition	-0.040	-0.035	0.053
	BRNS – Presidents	-0.075	-0.158	-0.065
Executive Functioning	DRS-Initiation/Perseveration	0.019	-0.131	-0.165
	DRS-Conceptualization	0.075	-0.008	-0.236*
	Trails B – Errors	-0.125	0.079	0.347*
	Trails B – Time	-0.186	-0.010	0.278*
	CVLT-I – Intrusions	0.110	0.101	-0.183*
	CVLT-I – False Positives	-0.266*	0.049	0.475*
Language Functioning	BNT	0.025	-0.206*	-0.139
	Semantic Fluency	0.131	-0.084	-0.225*
	Phonemic Fluency (FAS)	0.209*	0.101	0.005
	BRNS - Reading	N/A**	N/A**	N/A**
	BRNS - Writing	0.147	-0.064	-0.002
	BRNS - Comprehension	0.052	0.065	0.135
	BRNS - Repetition	0.013	0.031	0.055

*indicates significance, $p<0.05$ or less
** incomplete data

Table 16: Experiment 2 - ANOVA Source Table With Omission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	0.15	1	0.15	1.25	0.27, n.s.
Error	3.24	27	0.12		
Within Subjects					
Density	1.20	2	0.60	23.99	<.0001*
TDR	0.40	4	0.10	4.01	0.003*
Group x Density	0.005	2	0.003	0.11	.90, n.s.
Group x TDR	0.10	4	0.03	1.02	.40, n.s.
Density x TDR	0.73	8	0.09	3.68	0.0004*
Group x Density x TDR	0.16	8	0.02	0.80	.60, n.s.
Error	9.41	378	0.02		

*indicates significance, $p<0.05$ or less

Table 17: Experiment 2 - ANOVA Source Table With Commission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	4.13	1	4.13	15.74	0.0005*
Error	7.09	27	0.26		
Within Subjects					
Density	0.29	2	0.14	4.44	0.012*
TDR	0.28	4	0.07	2.21	0.066, trend
Group x Density	0.14	2	0.07	2.17	0.12, n.s.
Group x TDR	0.13	4	0.03	1.03	0.39, n.s.
Density x TDR	2.82	8	0.35	10.97	<0.0001*
Group x Density x TDR	1.66	8	0.21	6.45	<0.0001*
Error	12.14	378	0.03		

*indicates significance, $p<0.05$ or less

Table 18: Experiment 2 - ANOVA Source Table With Completion time as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	11.47	1	11.47	8.24	0.008*
Error	37.57	27	1.39		
Within Subjects					
Density	75.19	2	37.59	915.70	<0.0001*
TDR	9.15	4	2.29	55.78	<0.0001*
Group x Density	0.18	2	0.09	2.14	0.12, n.s.
Group x TDR	0.57	4	0.14	3.46	0.009*
Density x TDR	1.64	8	0.20	4.98	<0.0001*
Group x Density x TDR	0.16	8	0.02	0.49	0.87, n.s.
Error	15.52	378	0.04		

*indicates significance, $p<0.05$ or less

Table 19: Experiment 2 - ANOVA Source Table With Time Per Total Cancellations as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	4.84	1	4.84	3.37	0.078, trend
Error	38.86	27	1.44		
Within Subjects					
Density	0.30	2	0.15	2.26	0.11, n.s.
TDR	17.59	4	29.40	444.51	<0.0001*
Group x Density	0.36	2	0.18	2.70	0.069, trend
Group x TDR	0.41	4	0.10	1.53	0.19, n.s.
Density x TDR	1.47	8	0.18	2.77	0.005*
Group x Density x TDR	0.50	8	0.06	0.94	0.49, n.s.
Error	25.00	378	0.07		

*indicates significance, $p<0.05$ or less

Table 20: Experiment 2 - ANOVA Source Table for Order of Presentation With Omission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	0.15	1	0.15	1.25	0.27, n.s.
Error	3.24	27	0.12		
Within Subjects					
Order of Presentation	0.42	14	0.03	1.03	0.42, n.s.
Group x Order	0.52	14	0.04	1.26	0.23, n.s.
Error	11.07	378	0.03		

Table 21: Experiment 2 - ANOVA Source Table for Order of Presentation With Commission Errors as the Dependent Variable.

Source	SS	df	MS	F	p
Between Subjects					
Group	4.13	1	4.13	15.74	0.005*
Error	7.09	27	0.26		
Within Subjects					
Order of Presentation	1.09	14	0.08	1.91	0.02*
Group x Order	0.86	14	0.06	1.50	0.11, n.s.
Error	15.50	378	0.04		

*indicates significance, $p<0.05$ or less

Table 22: Experiment 2 – Spearman Correlations for Omissions, Commission, and Completion Time with Select Neuropsychological Tests: Alzheimer's Disease

Cognitive Function Assessed	Neuropsychological Test	Correlation with Omissions (Critical Rho Value)	Correlation with Commissions (Critical Rho Value)	Correlation with Completion Time (Critical Rho Value)
Severity Screening	MMSE	-0.214*	-0.150	-0.064
	DRS-Total	-0.186*	-0.162	-0.031
Attentional Functioning	DRS-Attention	-0.221*	-0.248*	0.132
	Trails A – Errors	-0.018	-0.044	-0.046
	Trails A – Time	0.279*	0.415*	0.200
	Digit Coding Percentile	-0.247	-0.403*	-0.075
	Line Cancellation – Errors	0.175	0.271*	0.051
	Line Cancellation – Time	0.115	0.222*	0.350*
	Digit Span - Forward	-0.101	-0.101	0.117
	Digit Span - Backward	-0.236*	-0.168	-0.035
	Digit Span - Total	-0.192*	-0.132	0.069
	Visual Span - Forward	-0.293*	-0.291*	-0.091
	Visual Span - Backward	-0.197*	-0.137	-0.140
	Visual Span – Total	-0.273*	-0.243*	-0.131

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Memory Functioning	DRS-Memory	0.052	0.062	0.011
	CVLT-I – Short Delay Free Recall	0.108	0.115	-0.219*
	CVLT-I – Long Delay Free Recall	0.118	0.173	-0.106
	CVLT-I – Recency	-0.100	-0.161	0.232*
	BRNS – Immediate Visual Recall	-0.191	-0.164	-0.194
	BRNS – Immediate Story Recognition	-0.082	-0.343*	0.131
	BRNS – Long Delay Free Story Recall	0.000	0.055	0.019
	BRNS – Delayed Visual Recognition	-0.008	-0.126	-0.089
	BRNS – Presidents	-0.144	-0.046	-0.321*
Executive Functioning	DRS-Initiation/Perseveration	-0.150	-0.041	-0.202*
	DRS-Conceptualization	-0.104	-0.253*	0.111
	Trails B – Errors	0.109	-0.086	0.156
	Trails B – Time	0.183	0.034	0.352*
	CVLT-I – Intrusions	-0.081	-0.073	-0.210*
	CVLT-I – False Positives	-0.075	0.073	0.077
Language Functioning	BNT	-0.184	-0.301*	-0.280*
	Semantic Fluency	-0.194	-0.264*	-0.115
	Phonemic Fluency (FAS)	-0.177	-0.158	-0.085
	BRNS - Reading	-0.175	-0.271*	-0.051
	BRNS - Writing	0.187	0.025	-0.187
	BRNS - Comprehension	-0.166	-0.249*	-0.228*
	BRNS - Repetition	-0.195	-0.216*	0.132

*indicates significance, $p<0.05$ or less

Table 23: Experiment 2 – Spearman Correlations for Omissions, Commission, and Completion Time with Select Neuropsychological Tests – Controls.

Cognitive Function Assessed	Neuropsychological Test	Correlation with Omissions (Critical Rho Value)	Correlation with Commissions (Critical Rho Value)	Correlation with Completion Time (Critical Rho Value)
Severity Screening	MMSE	-0.060	-0.135	-0.232*
	DRS-Total	0.015	-0.120	-0.153
Attentional Functioning	DRS-Attention	0.018	0.090	0.054
	Trails A – Errors	-0.018	-0.090	-0.054
	Trails A – Time	0.024	0.196*	0.186
	Digit Coding Percentile	-0.142	-0.149	-0.067
	Line Cancellation – Errors	N/A**	N/A**	N/A**
	Line Cancellation – Time	0.038	0.083	0.160
	Digit Span - Forward	-0.048	-0.152	-0.177
	Digit Span - Backward	-0.053	-0.136	0.020
	Digit Span - Total	-0.036	-0.128	-0.064
	Visual Span - Forward	-0.115	-0.139	-0.080
	Visual Span - Backward	-0.289*	-0.153	-0.006
	Visual Span – Total	0.198*	-0.141	-0.033

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Memory Functioning	DRS-Memory	0.077	0.061	-0.079
	CVLT-I – Short Delay Free Recall	0.123	-0.055	-0.115
	CVLT-I – Long Delay Free Recall	-0.009	-0.108	0.019
	CVLT-I – Recency	0.131	0.040	-0.120
	BRNS – Immediate Visual Recall	0.035	-0.074	-0.259*
	BRNS – Immediate Story Recognition	0.102	-0.124	-0.251*
	BRNS – Long Delay Free Story Recall	0.014	-0.093	-0.121
	BRNS – Delayed Visual Recognition	-0.030	-0.056	0.024
	BRNS – Presidents	-0.204*	-0.117	-0.043
Executive Functioning	DRS-Initiation/Perseveration	0.028	-0.161	-0.157
	DRS-Conceptualization	-0.042	-0.133	-0.207*
	Trails B – Errors	-0.011	0.141	0.277*
	Trails B – Time	-0.034	0.068	0.189*
	CVLT-I – Intrusions	0.093	-0.014	-0.135
	CVLT-I – False Positives	-0.241*	0.036	0.334*
Language Functioning	BNT	-0.142	-0.221*	-0.084
	Semantic Fluency	0.071	-0.095	-0.133
	Phonemic Fluency (FAS)	-0.002	0.014	0.129
	BRNS – Reading	N/A**	N/A**	N/A**
	BRNS – Writing	0.018	-0.034	0.084
	BRNS - Comprehension	-0.197*	-0.026	0.165
	BRNS - Repetition	0.135	0.046	0.025

*indicates significance, $p<0.05$ or less
** incomplete data

FIGURES

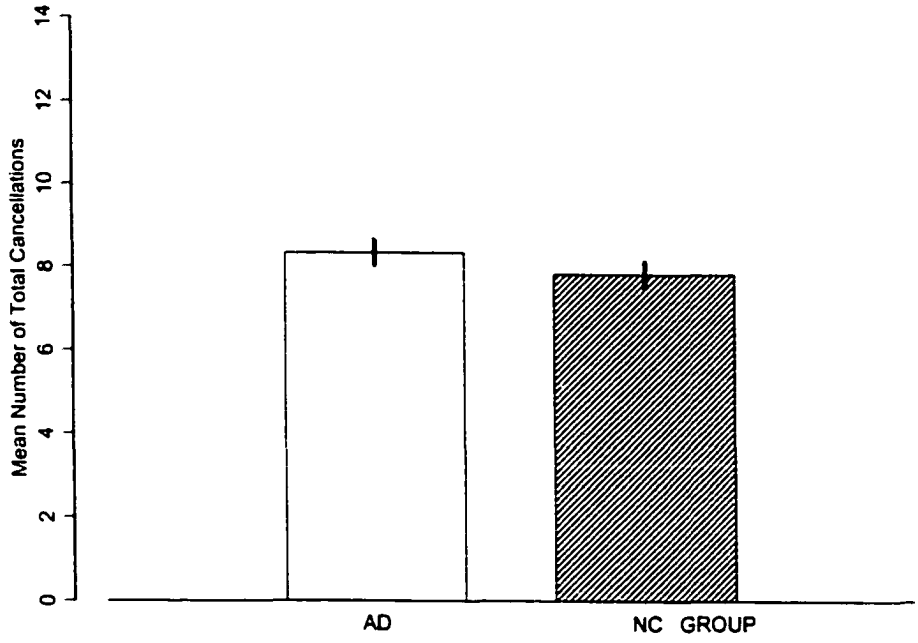


Figure 1. Expt1, Mean Number of Total Cancellations: Group (p=0.254, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

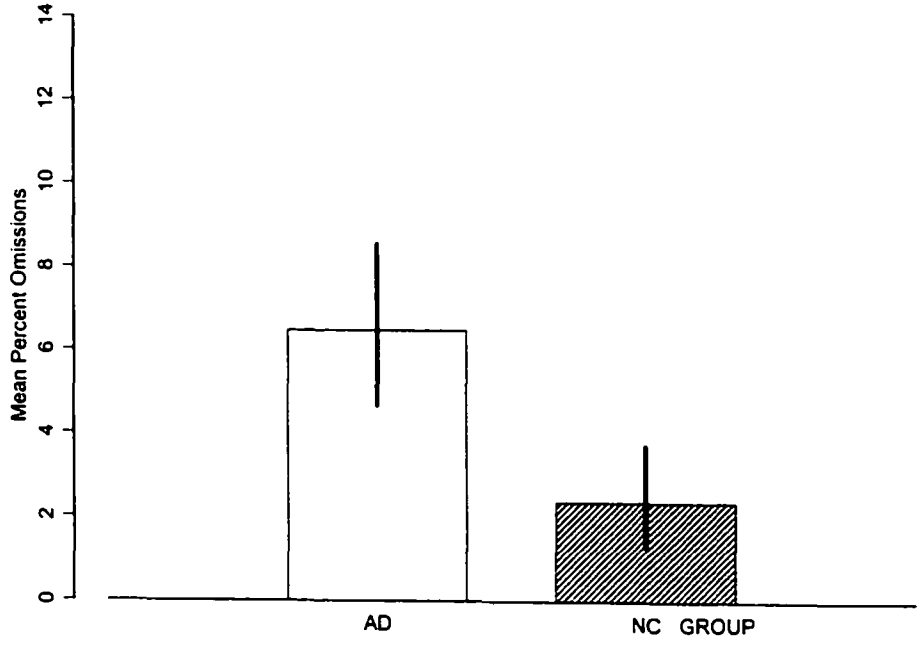


Figure 2. Expt 1, Mean Percent Omission Errors: Group (p=0.077, trend)

(NC = Normal controls; AD = Alzheimer's disease)

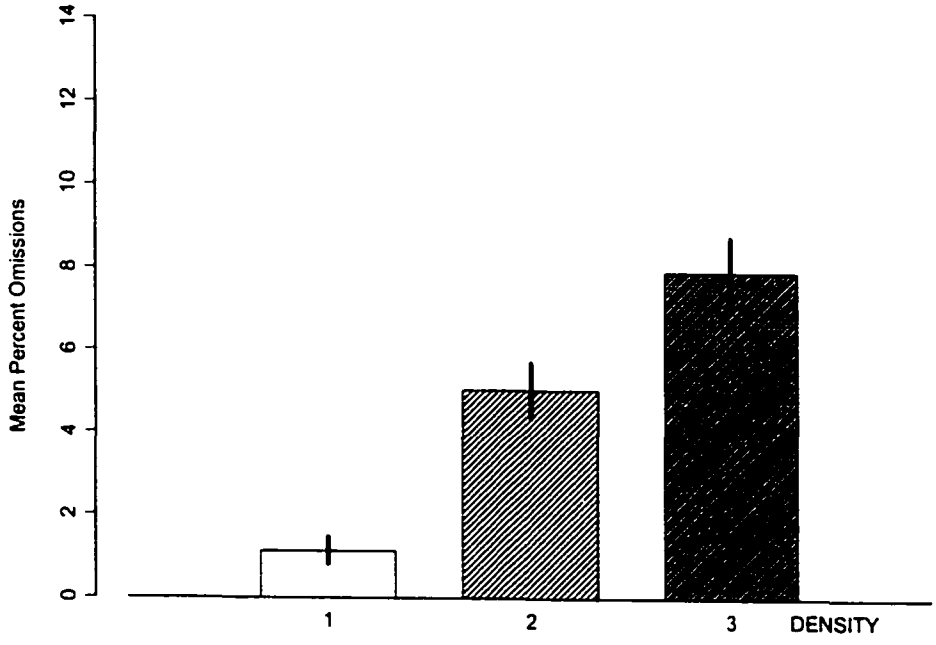


Figure 3. Expt 1, Mean Percent Omission Errors: Density ($p<.000001$)

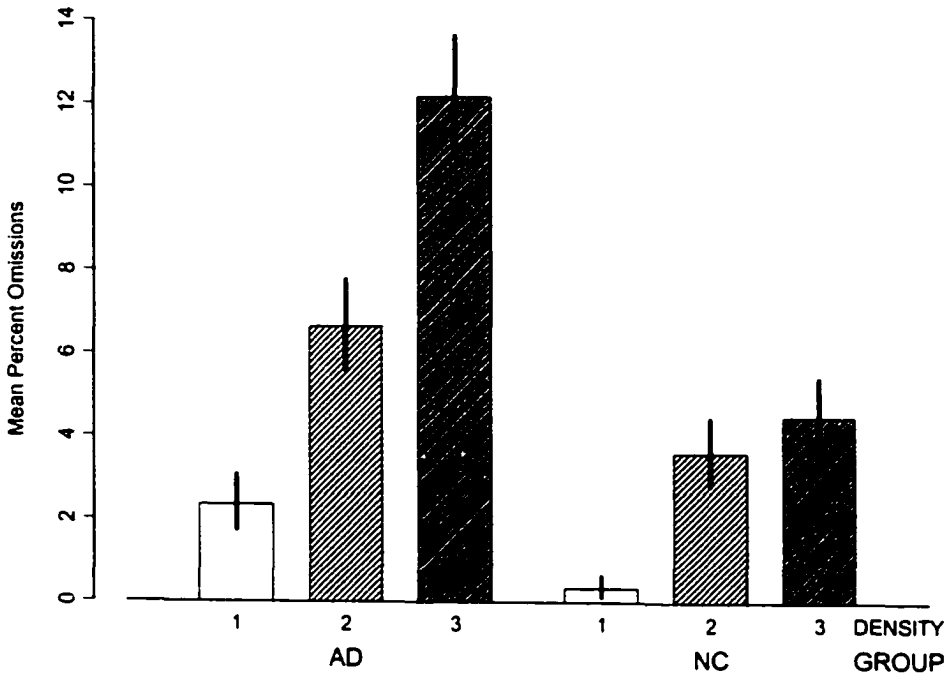


Figure 4. Expt 1, Mean Percent Omission Errors: Group x Density (n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

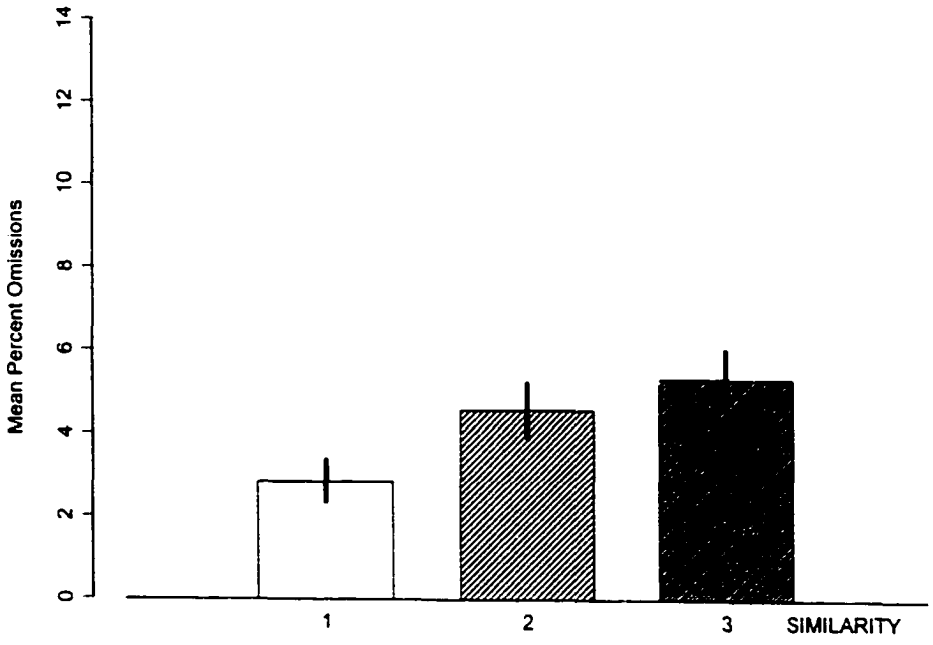


Figure 5. Expt 1, Mean Percent Omission Errors: Physical Similarity (p=0.011)

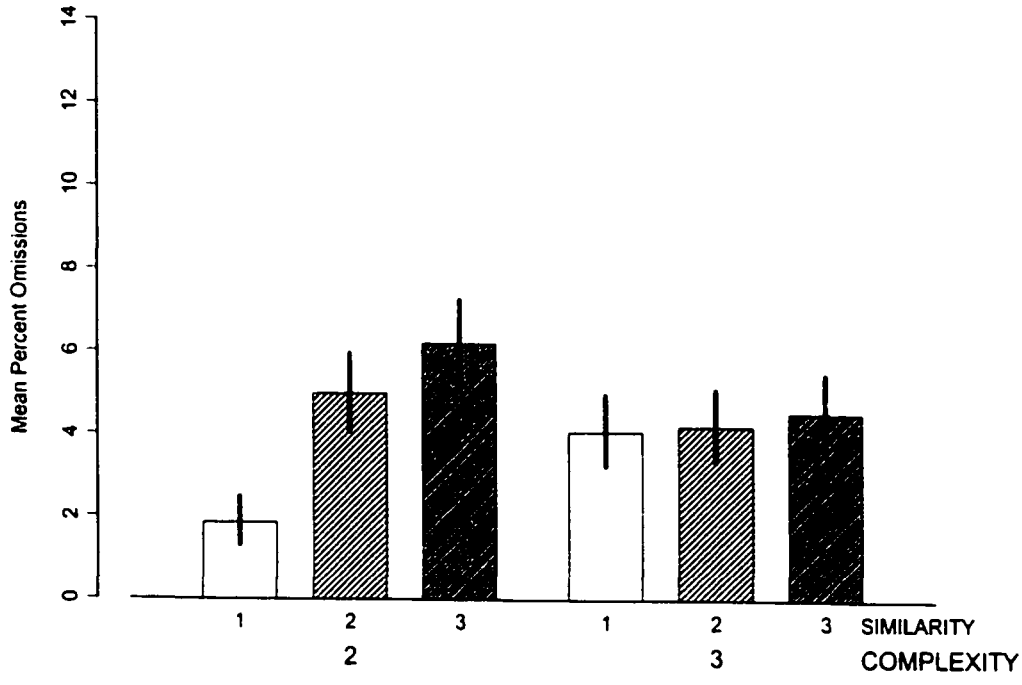


Figure 6. Expt 1, Mean Percent Omission Errors: Similarity x Complexity (p=.039)

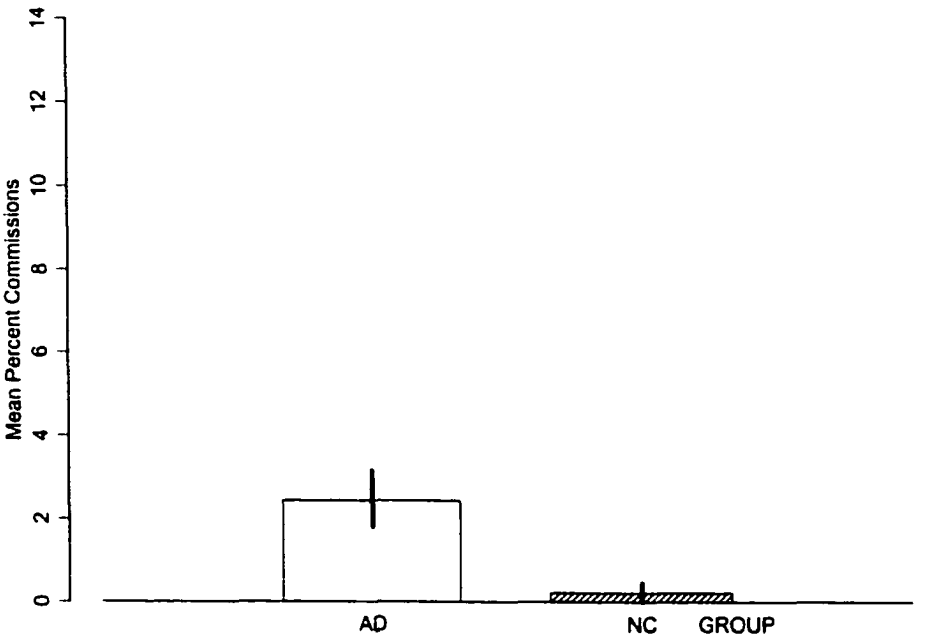


Figure 7. Expt 1, Mean Percent Commission Errors: Group (p=0.00132)

(NC = Normal controls; AD = Alzheimer's disease)

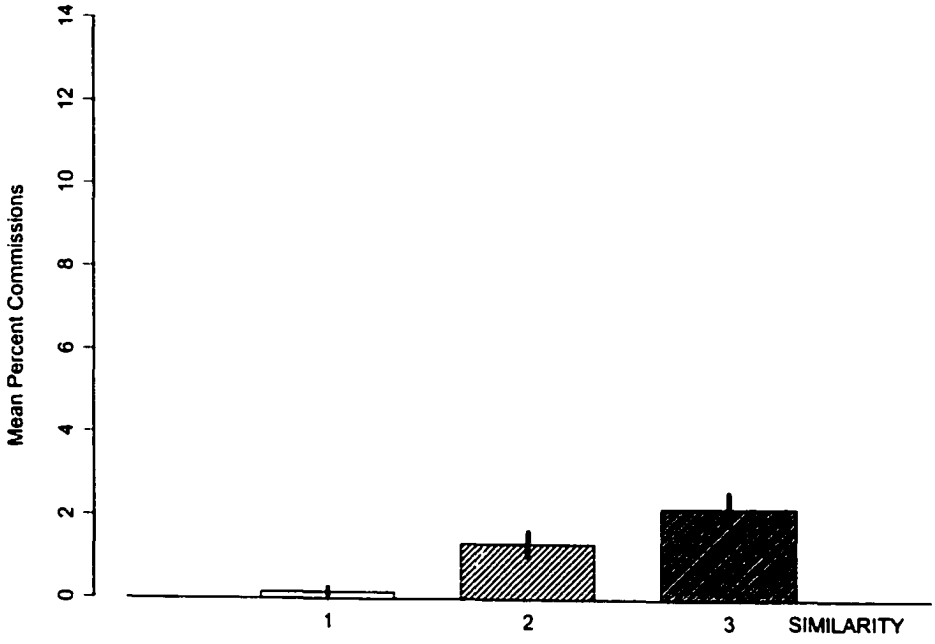


Figure 8. Expt 1, Mean Percent Commission Errors: Physical Similarity ($p<.00001$)

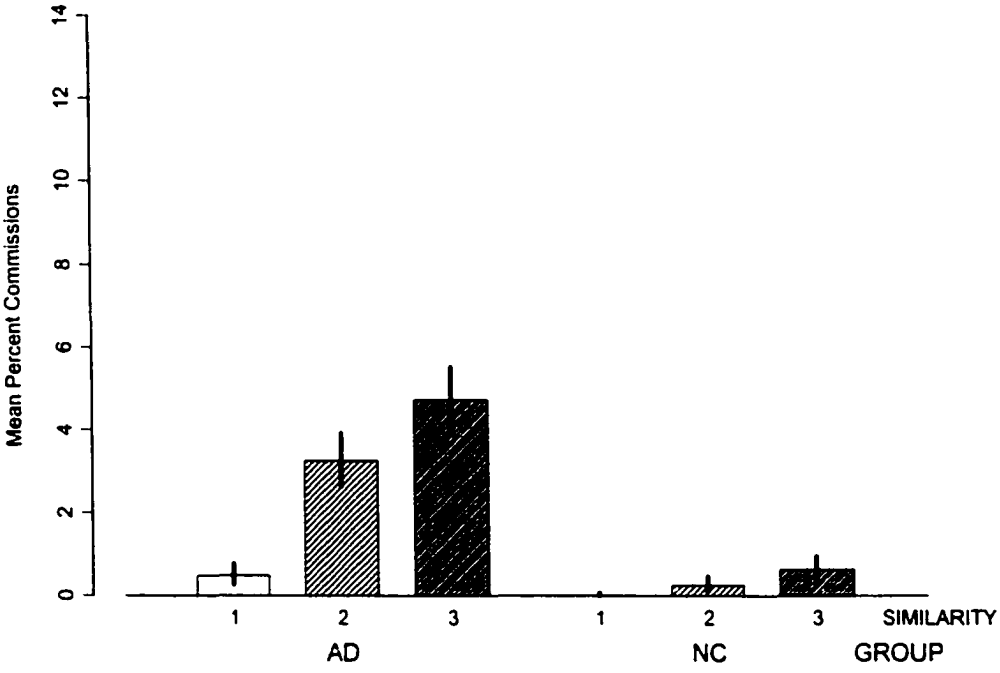


Figure 9. Expt 1, Mean Percent Commission Errors: Group x Similarity (p=.038)

(NC = Normal controls; AD = Alzheimer's disease)

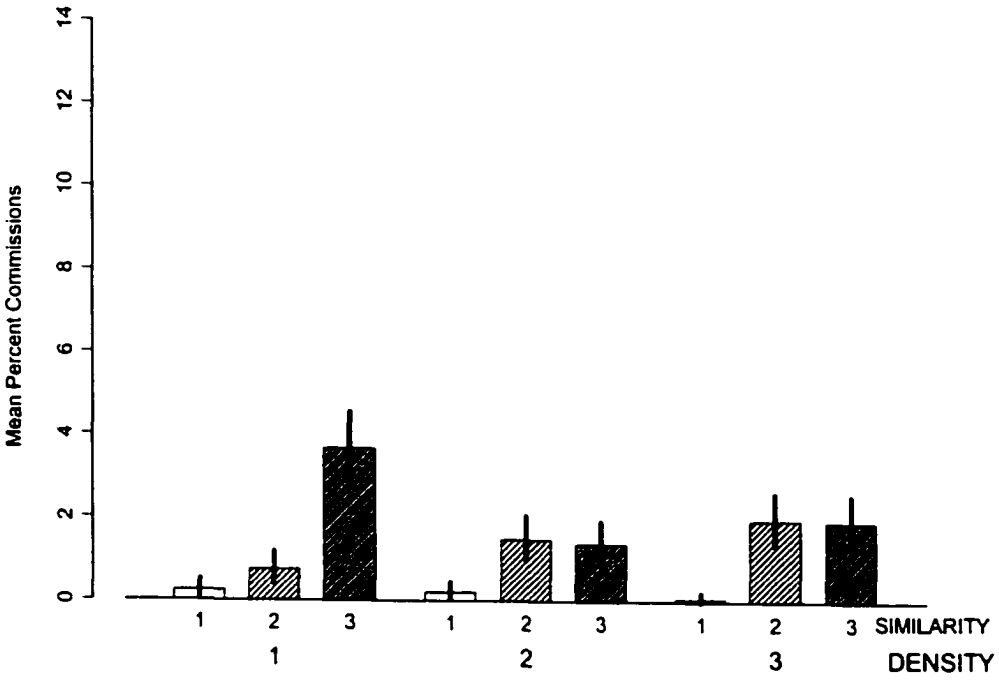


Figure 10. Expt 1, Mean Percent Commission Errors: Density x Similarity (p=.032)

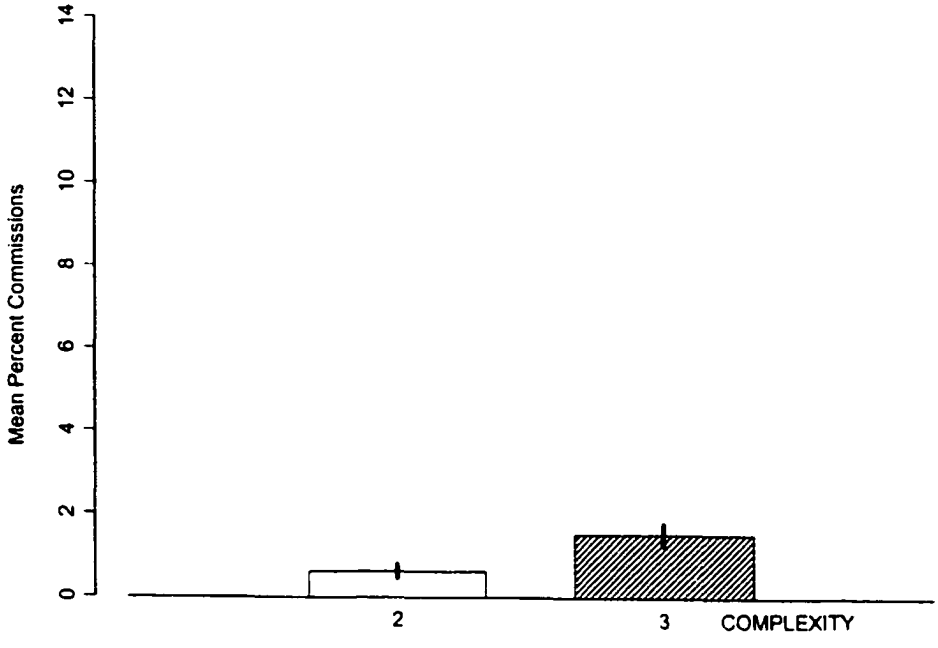


Figure 11. Expt 1, Mean Percent Commission Errors: Complexity (p=0.00123)

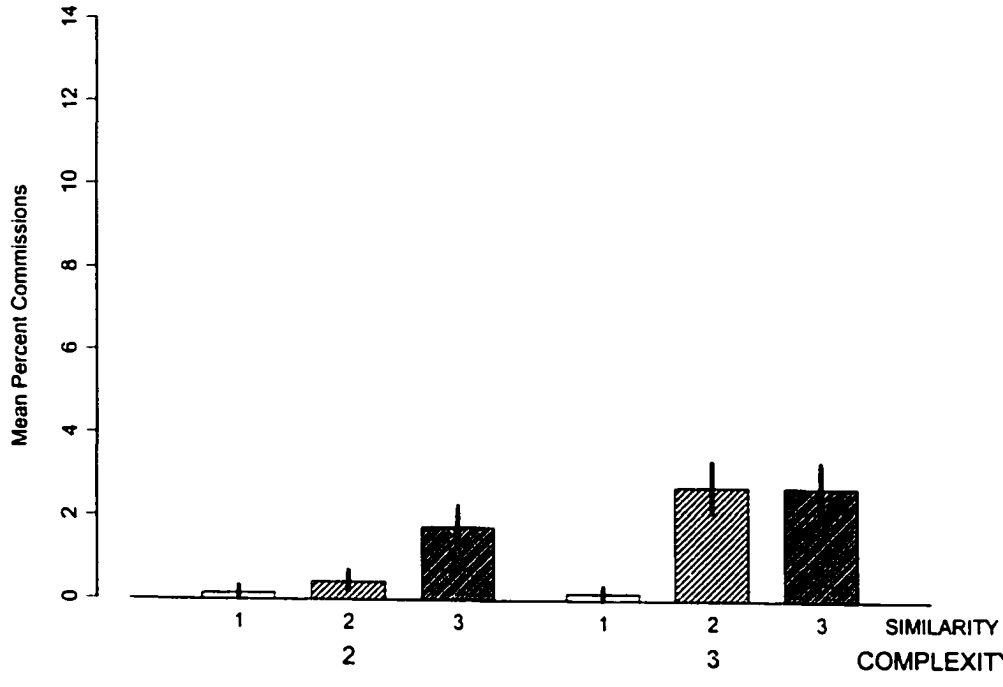


Figure 12. Expt 1, Mean Percent Commission Errors: Complexity x Similarity (p=.012)

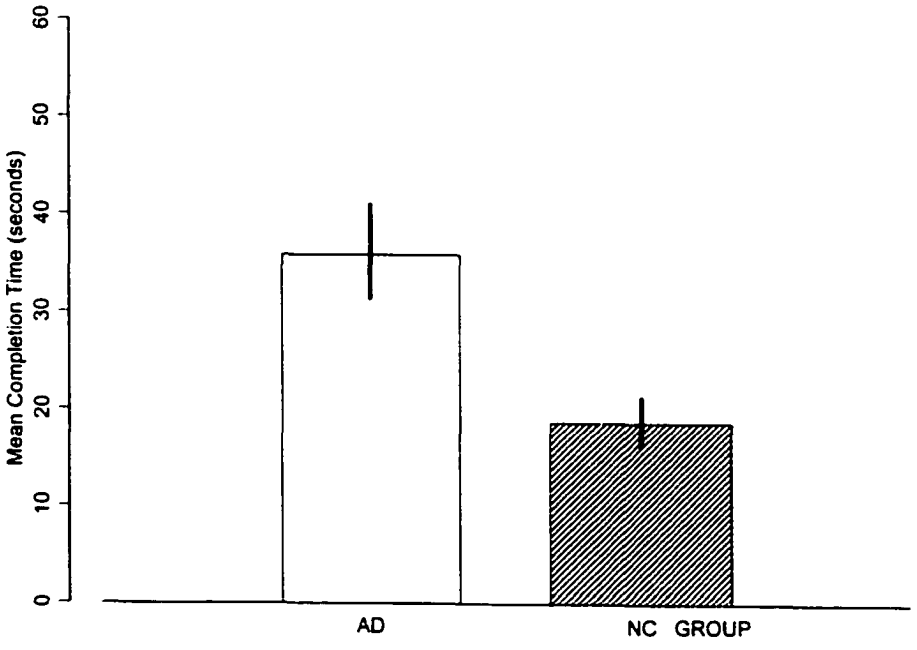


Figure 13. Expt 1, Mean Completion Time (seconds): Group (p=.0016)

(NC = Normal controls; AD = Alzheimer's disease)

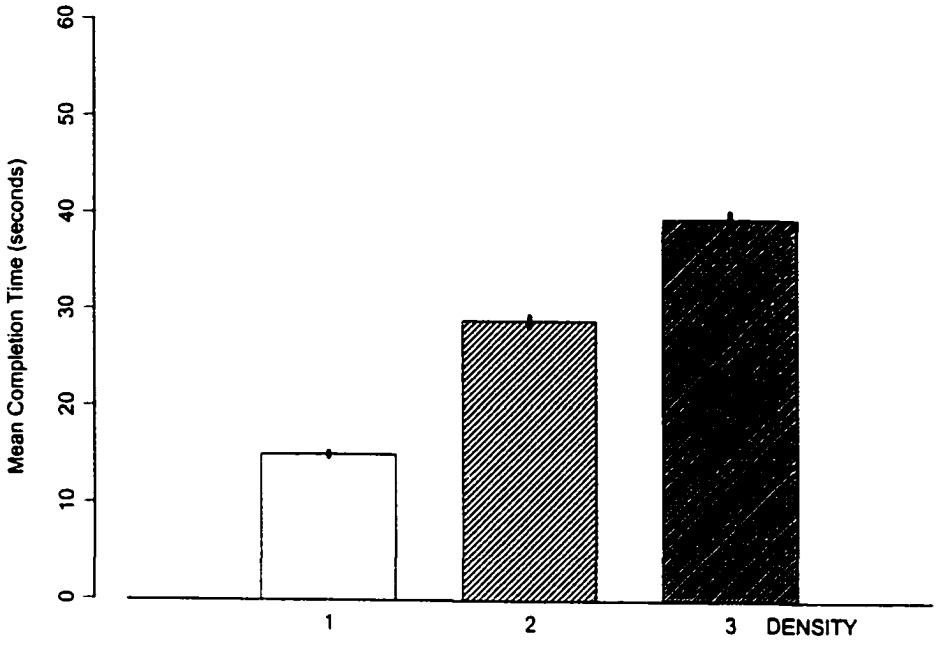


Figure 14. Expt 1, Mean Completion Time (seconds): Density ($p<.000001$)

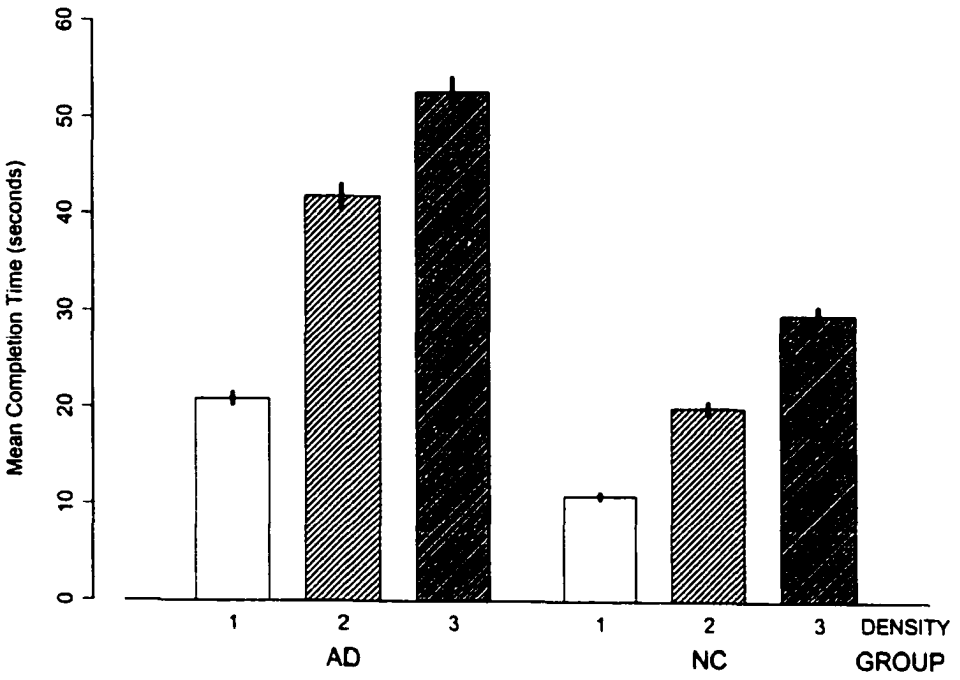


Figure 15. Expt 1, Mean Completion Time (seconds): Group x Density (p=.0166)

(NC = Normal controls; AD = Alzheimer's disease)

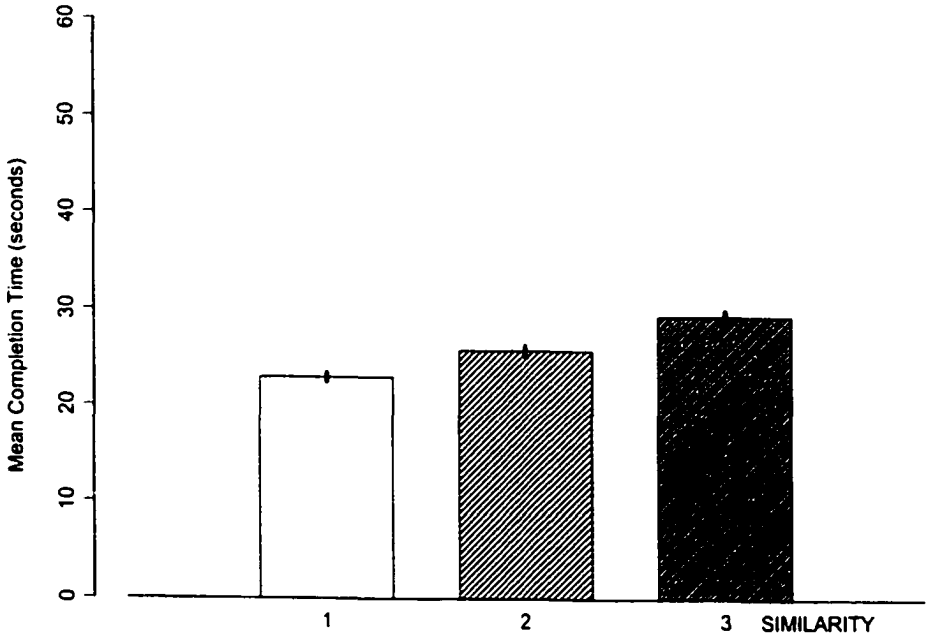


Figure 16. Expt 1, Mean Completion Time (seconds): Similarity ($p<.000001$)

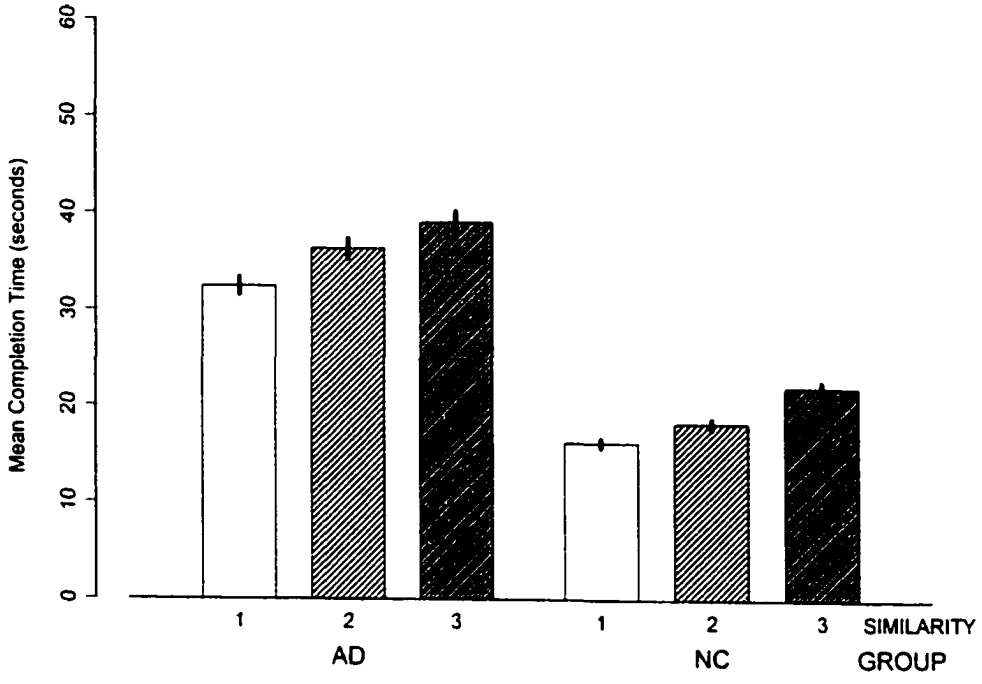


Figure 17. Expt 1, Mean Completion Time (seconds): Group x Similarity (p=.059, trend)

(NC = Normal controls; AD = Alzheimer's disease)

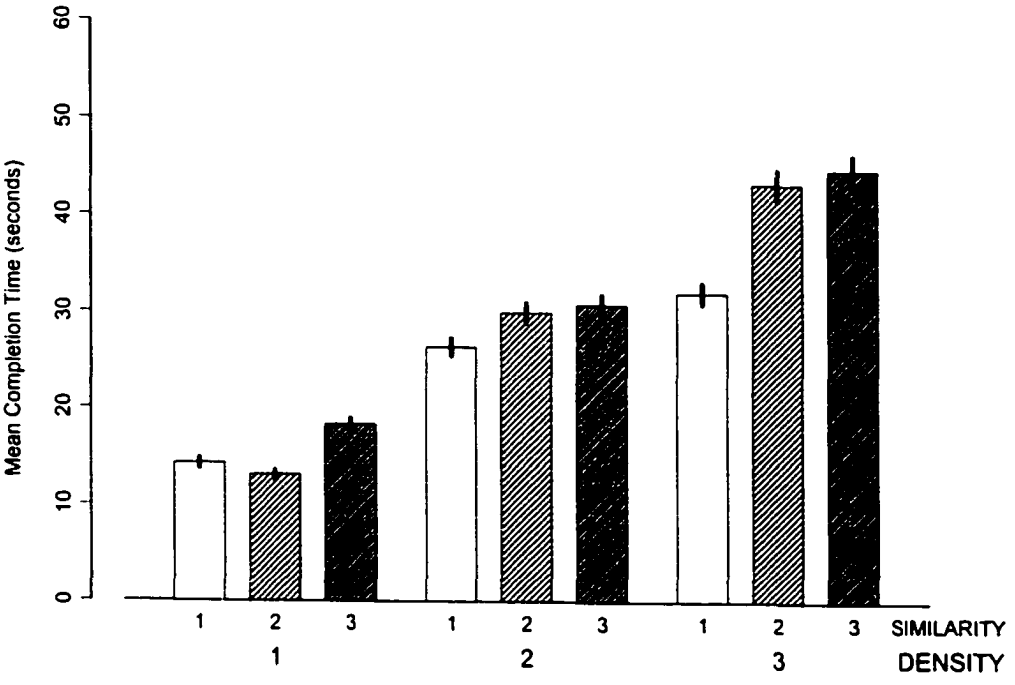


Figure 18. Expt 1, Mean Completion Time (seconds): Density x Similarity (p=<.00001)

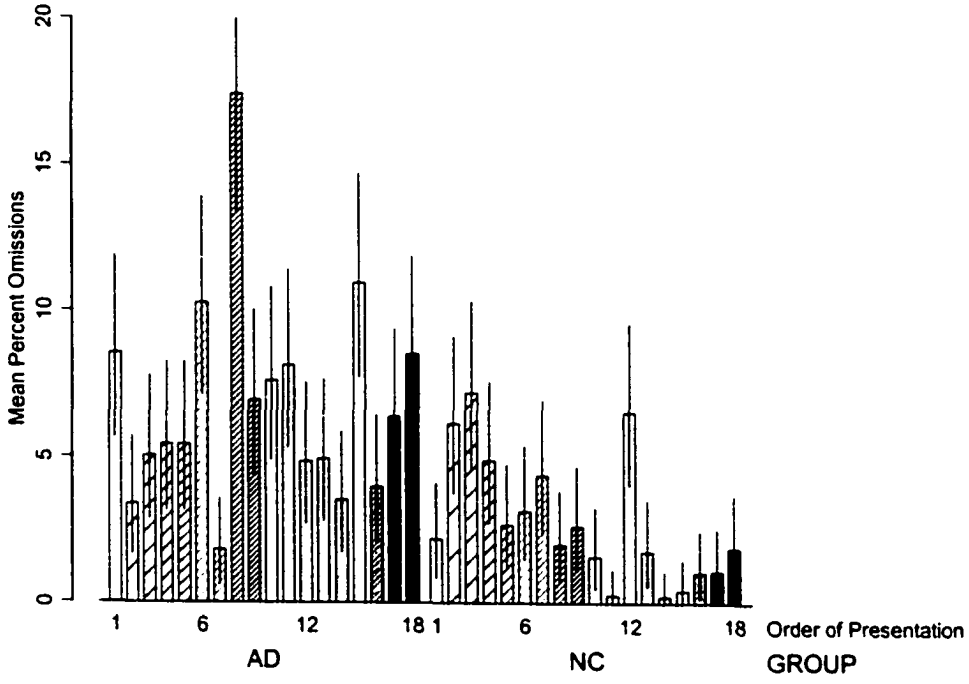


Figure 19. Expt 1, Order of Presentation, Mean % Omission Errors: Group x Order (p=0.014)

(NC = Normal controls; AD = Alzheimer's disease)

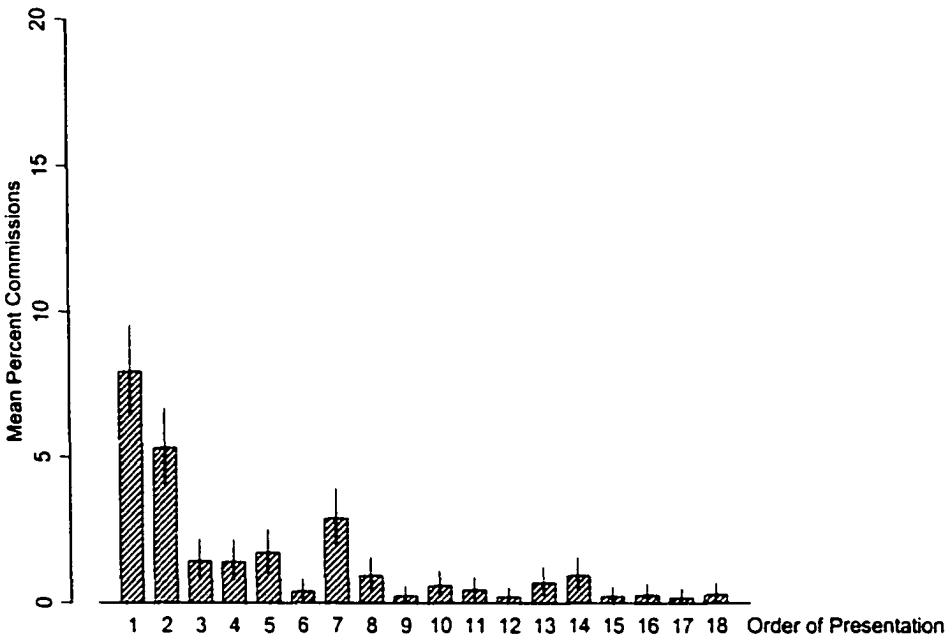


Figure 20. Expt 1, Order of Presentation, Mean % Commission Errors: Order ($p<.00001$)

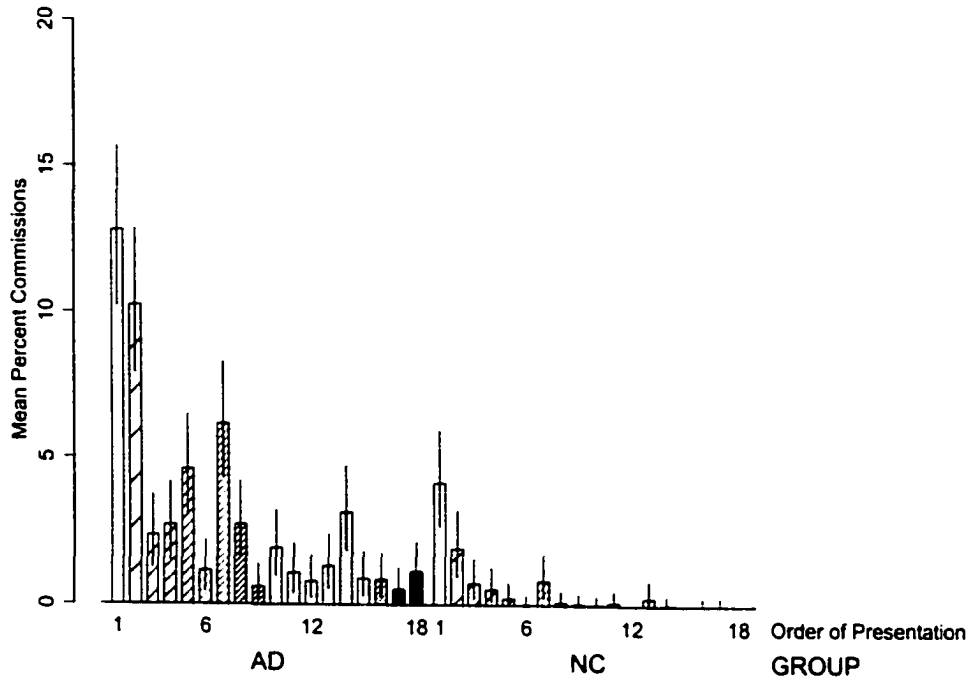


Figure 21. Exp 1, Order of Presentation, Mean % Commission Errors: Group x Order (p=0.950, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

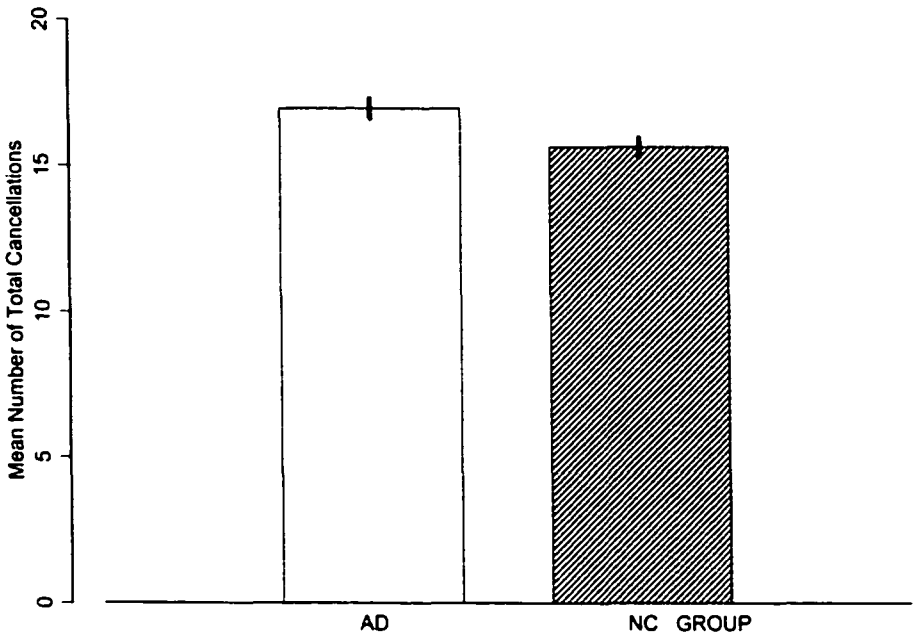


Figure 22. Expt 2, Mean Number of Total Cancellations: Group (p=0.012)

(NC = Normal controls; AD = Alzheimer's disease)

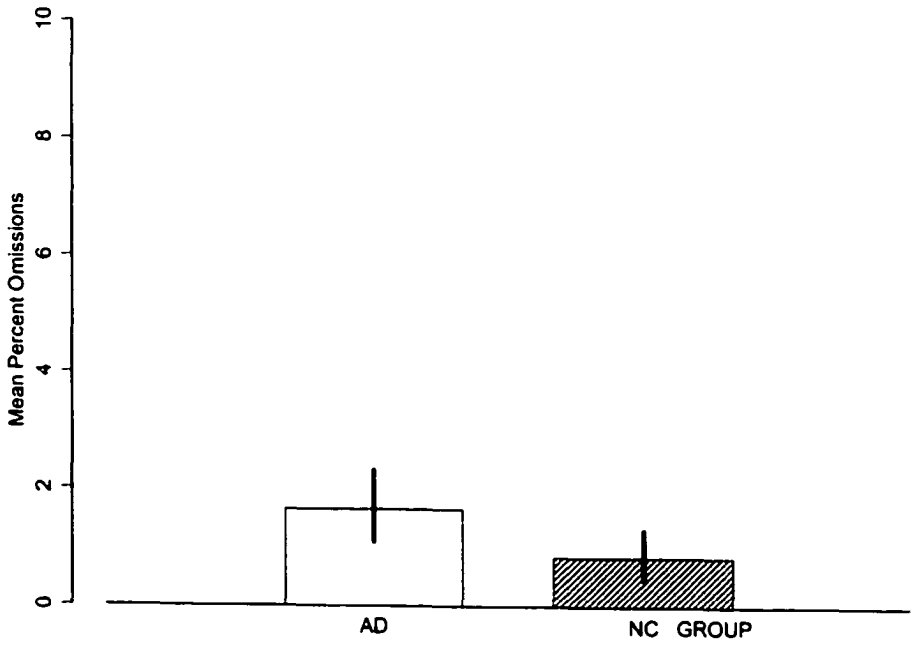


Figure 23. Expt 2, Mean Percent Omission Errors: Group (p=0.27, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

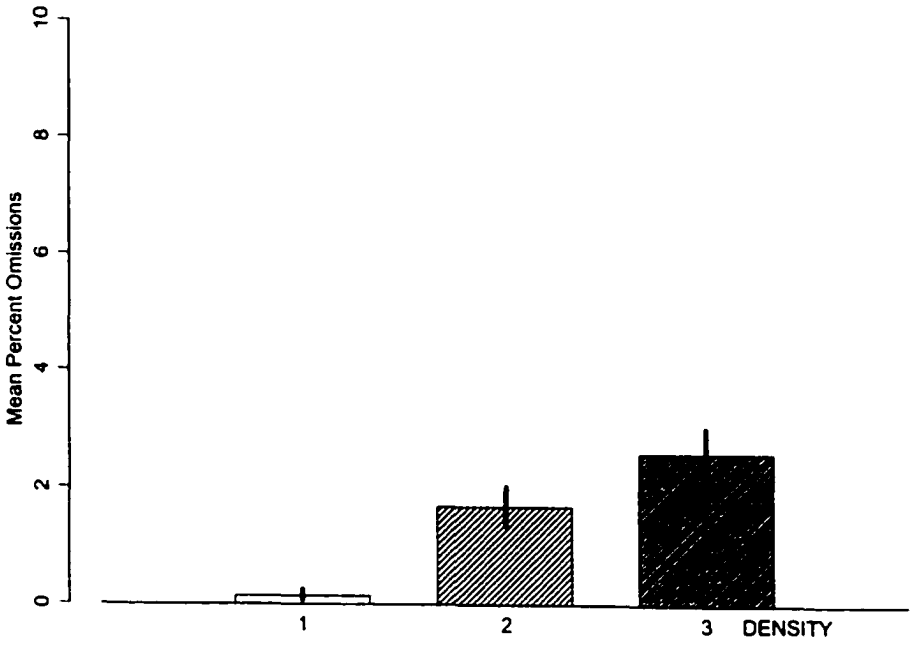


Figure 24. Expt 2, Mean Percent Omission Errors: Density ($p<.000001$)

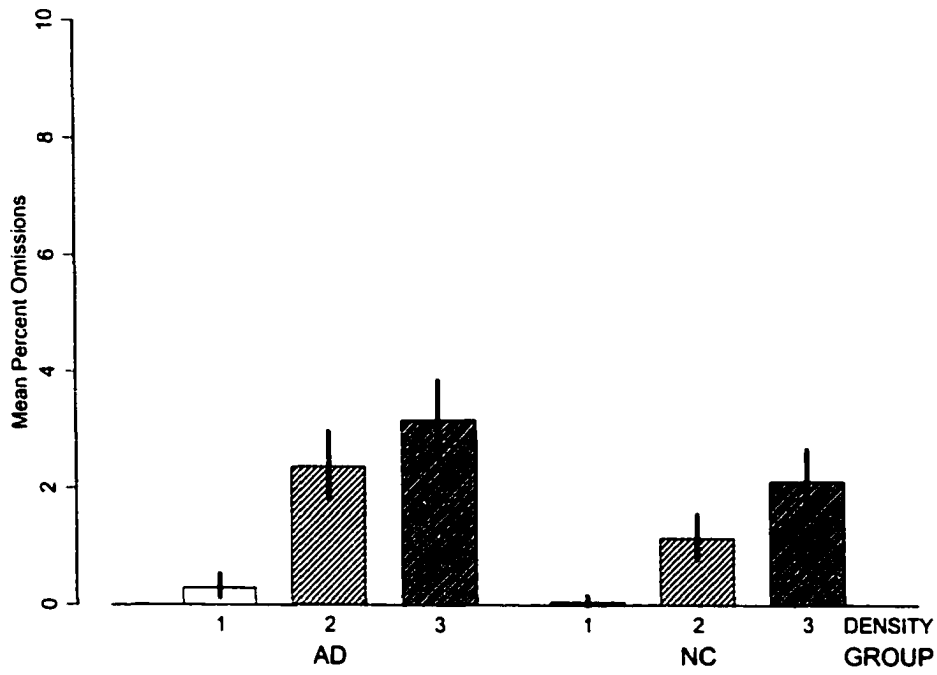


Figure 25. Expt 2, Mean Percent Omission Errors: Group x Density (0.90, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

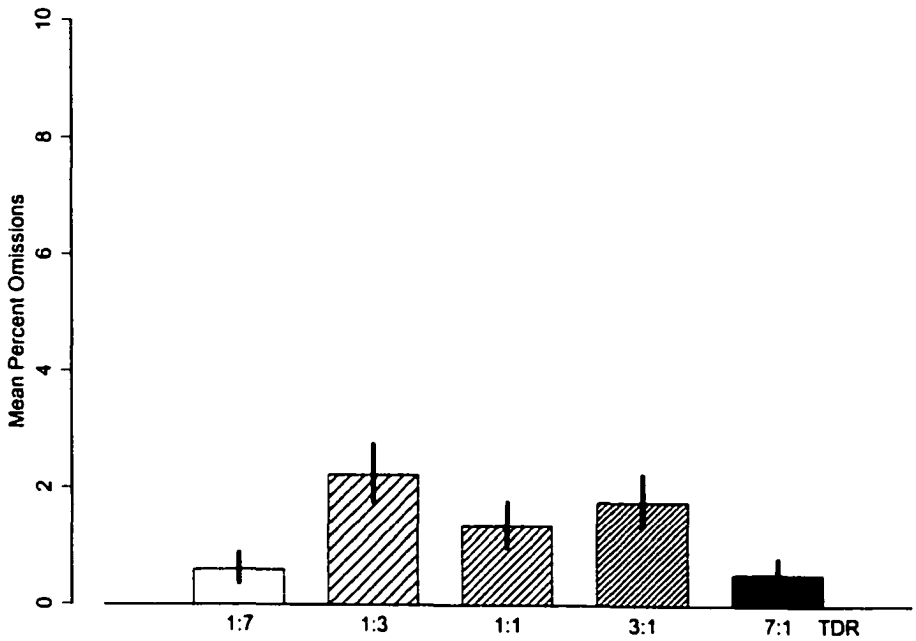


Figure 26. Expt 2, Mean Percent Omission Errors: TDR
(p=0.03)

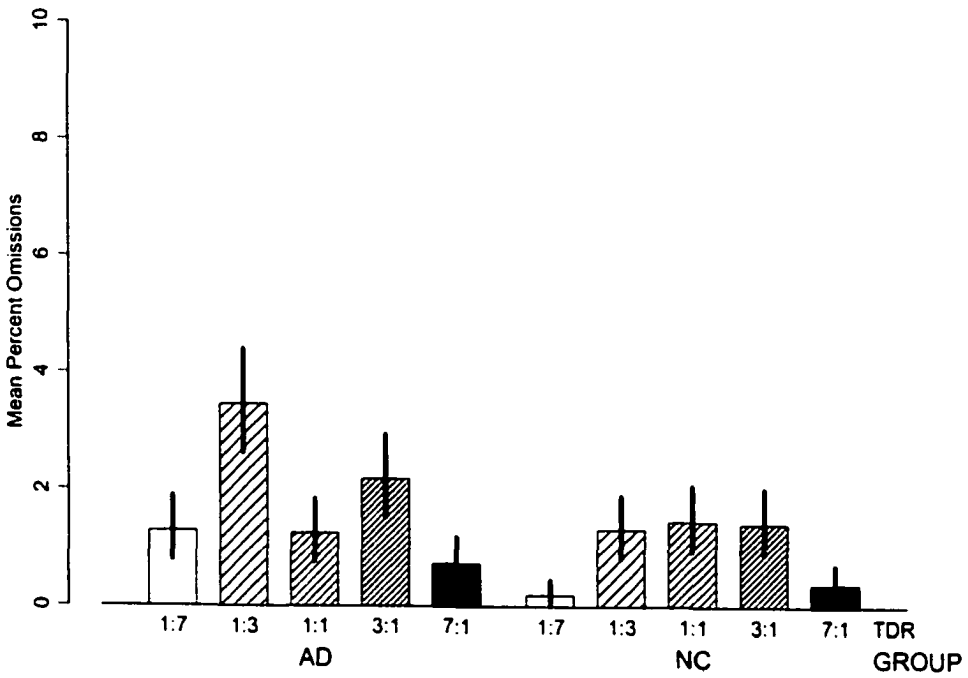


Figure 27. Expt 2, Mean Percent Omission Errors: Group x TDR (p=0.40, n.s.)

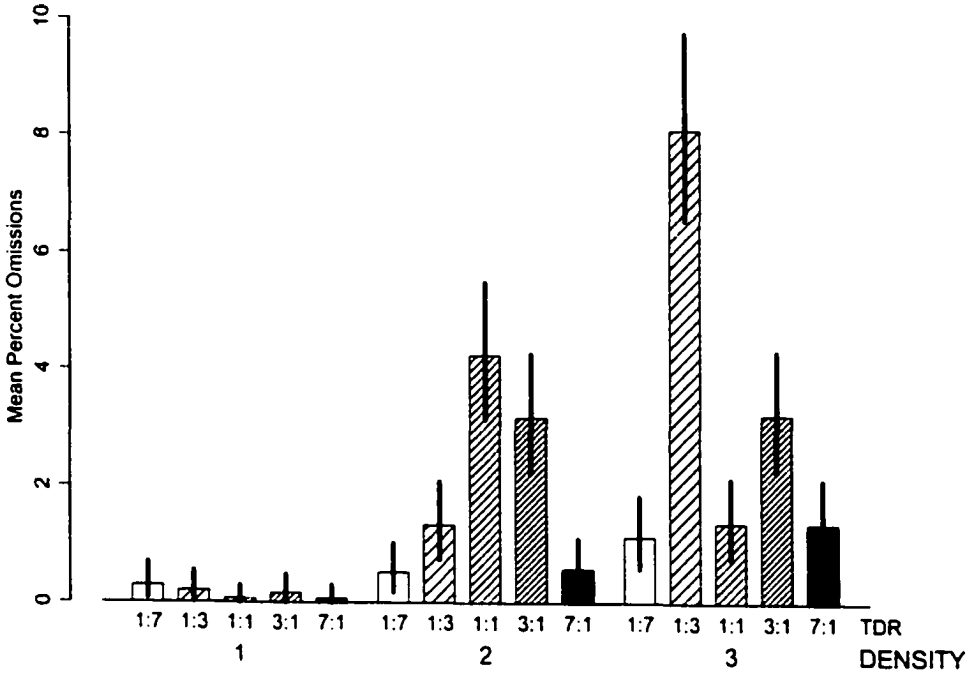


Figure 28. Expt 2, Mean Percent Omission Errors: Density x TDR (p=.0004)

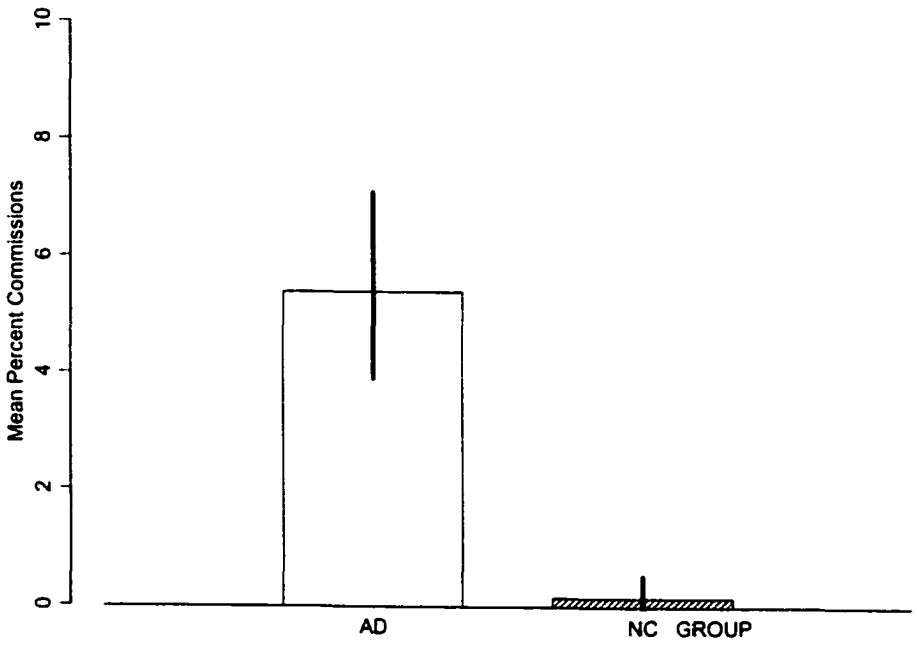


Figure 29. Expt 2, Mean Percent Commission Errors: Group (p=0.0005)

(NC = Normal controls; AD = Alzheimer's disease)

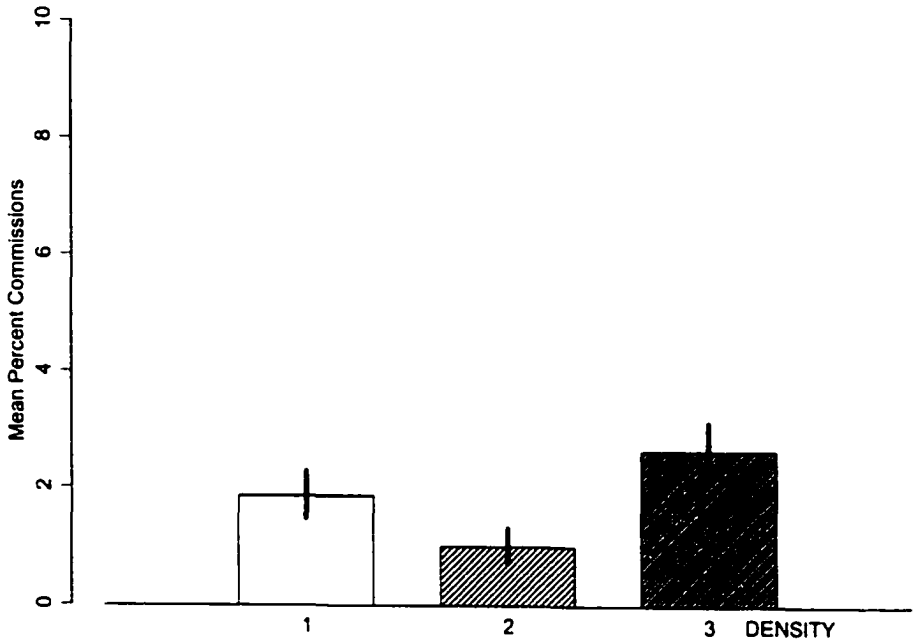


Figure 30. Expt 2, Mean Percent Commission Errors: Density (p=0.012)

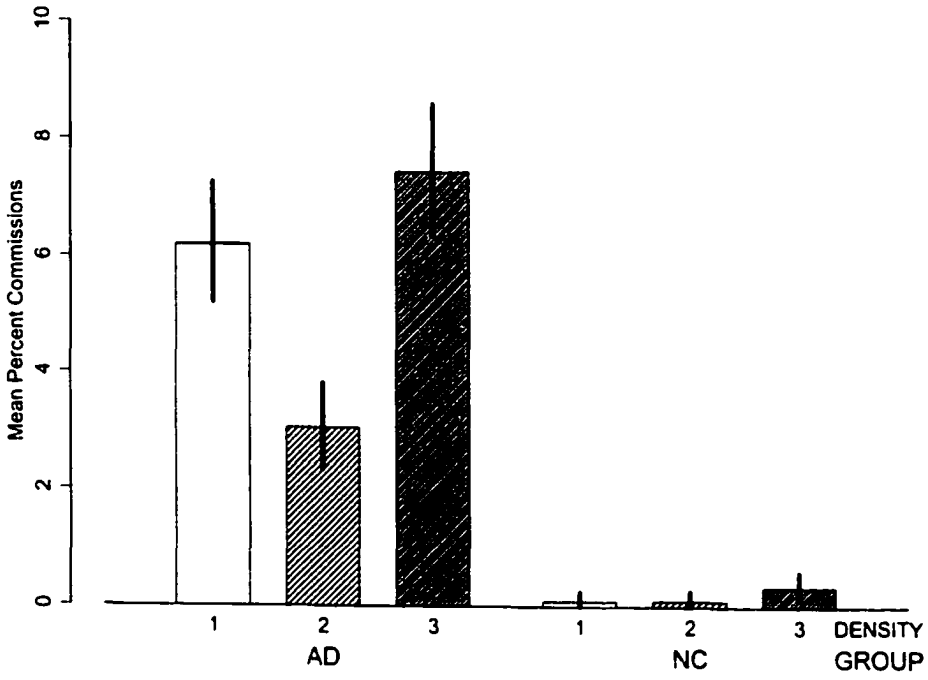


Figure 31. Expt 2, Mean Percent Commission Errors: Group x Density (p=.12, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

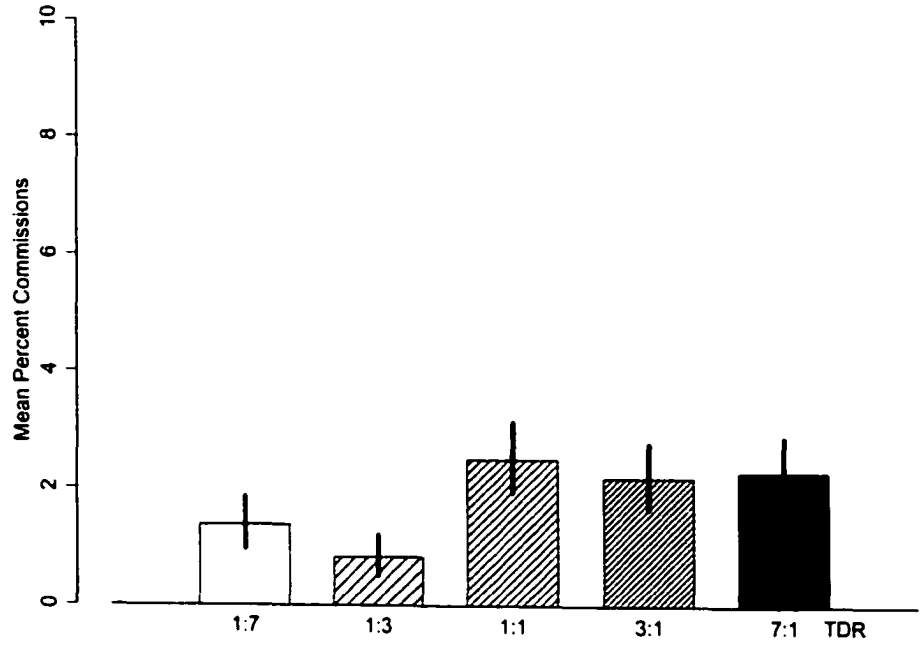


Figure 32. Expt 2, Mean Percent Commission Errors: TDR (p=0.066, trend)

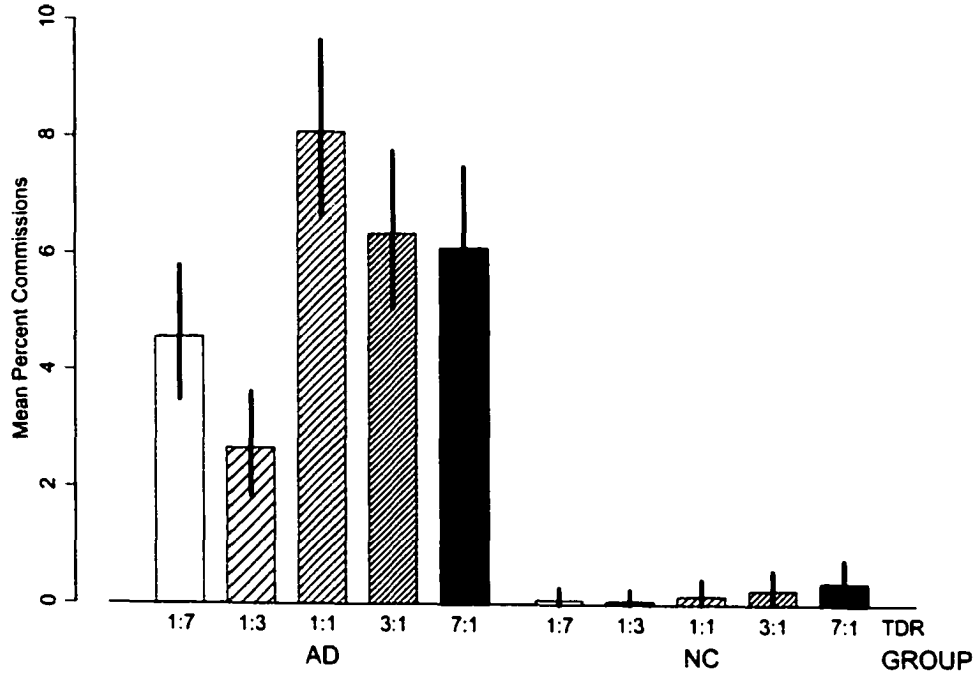


Figure 33. Expt 2, Mean Percent Commission Errors: Group x TDR (p=0.39, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

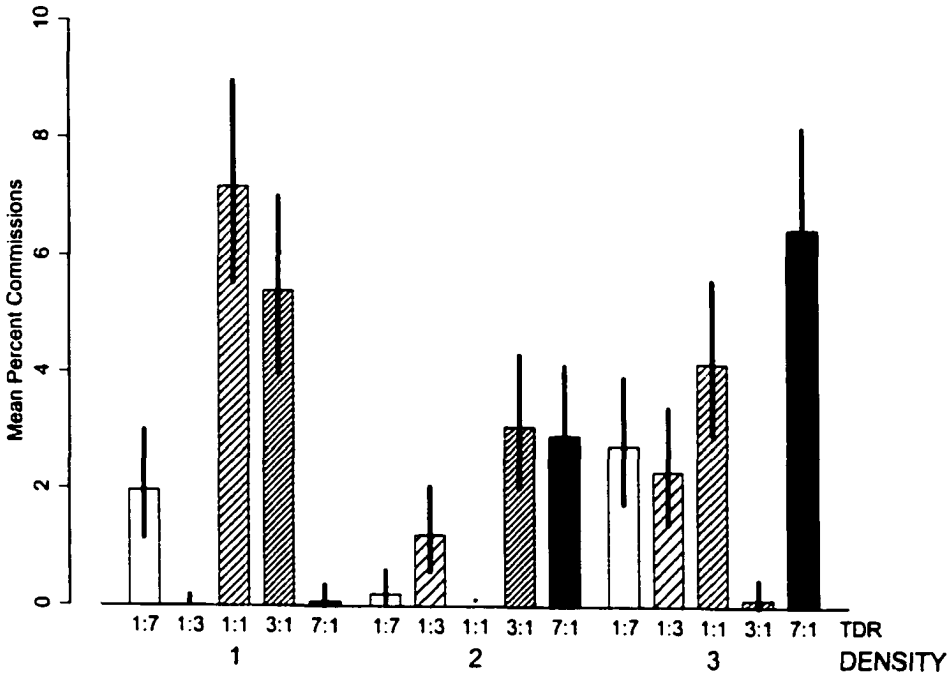


Figure 34. Expt 2, Mean Percent Commission Errors: Density x TDR ($p<.00001$)

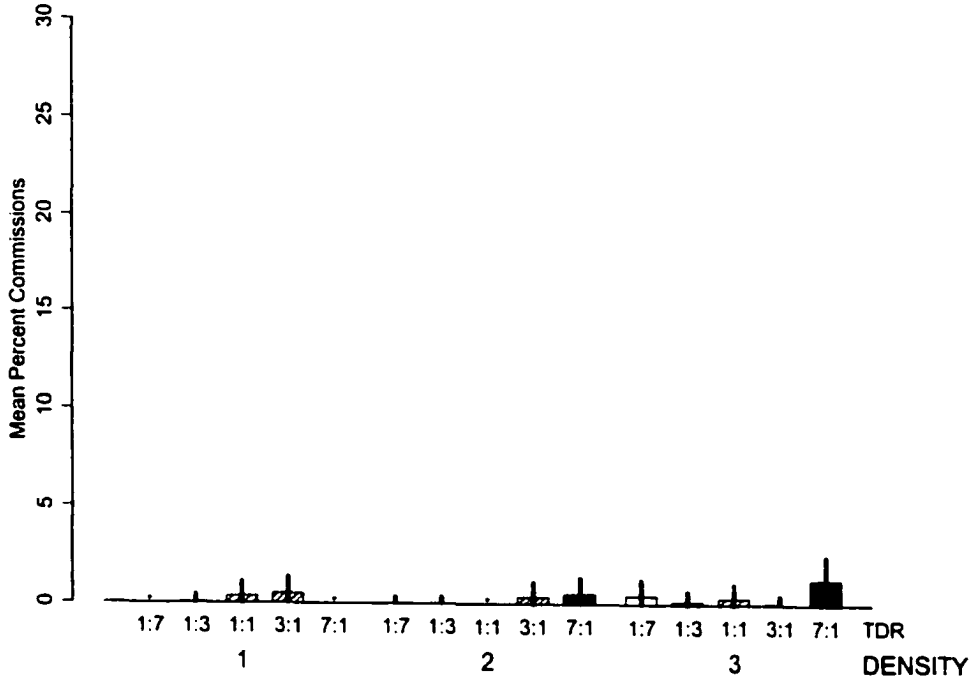


Figure 35. Expt 2, Mean Percent Commission Errors: Group x Density x TDR (Normal Control Group)
($p<.00001$)

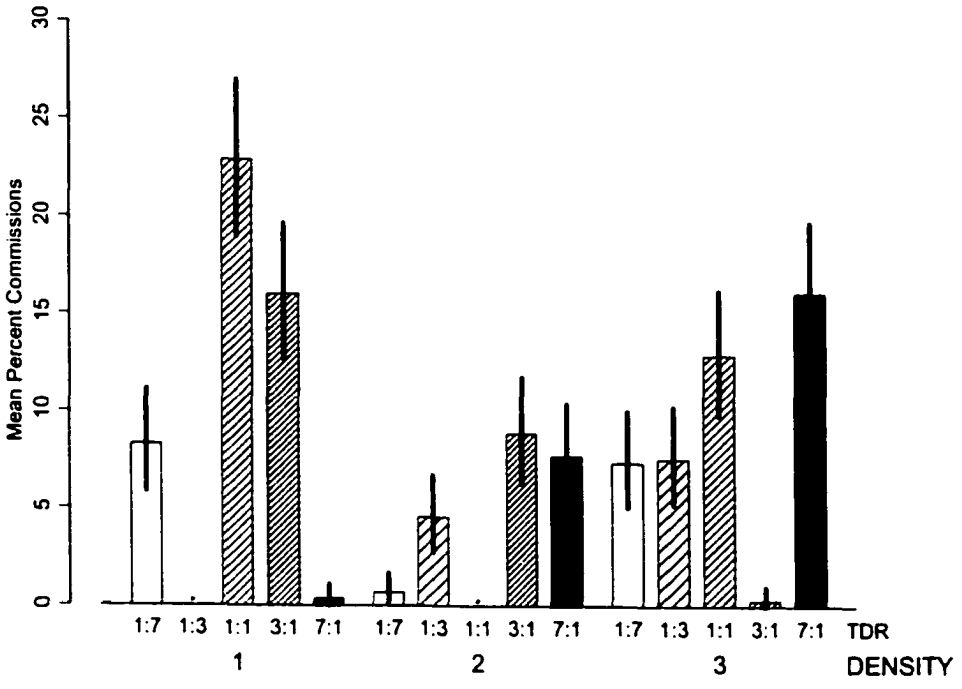


Figure 36. Expt 2, Mean Percent Commission Errors: Group x Density x TDR (Alzheimer's Disease Group)
($p<.00001$)

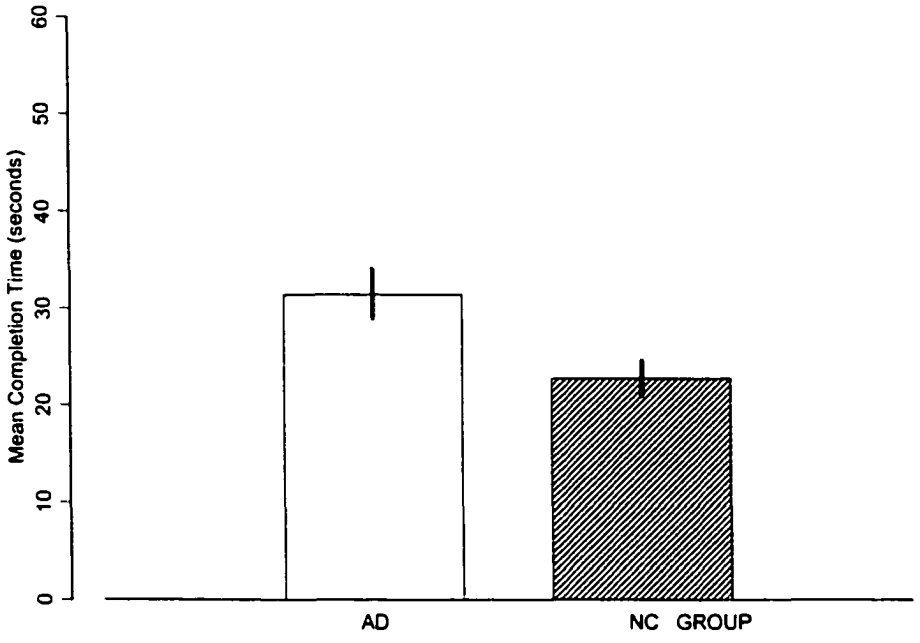


Figure 37. Expt 2, Mean Completion Time (seconds): Group (p=.008)

(NC = Normal controls; AD = Alzheimer's disease)

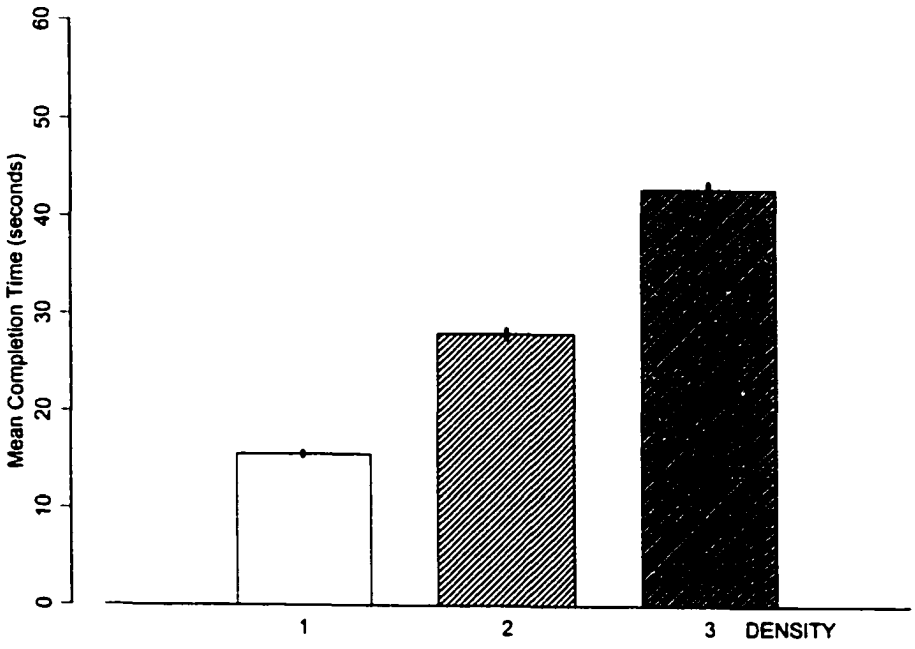


Figure 38. Expt 2, Mean Completion Time (seconds): Density ($p<.000001$)

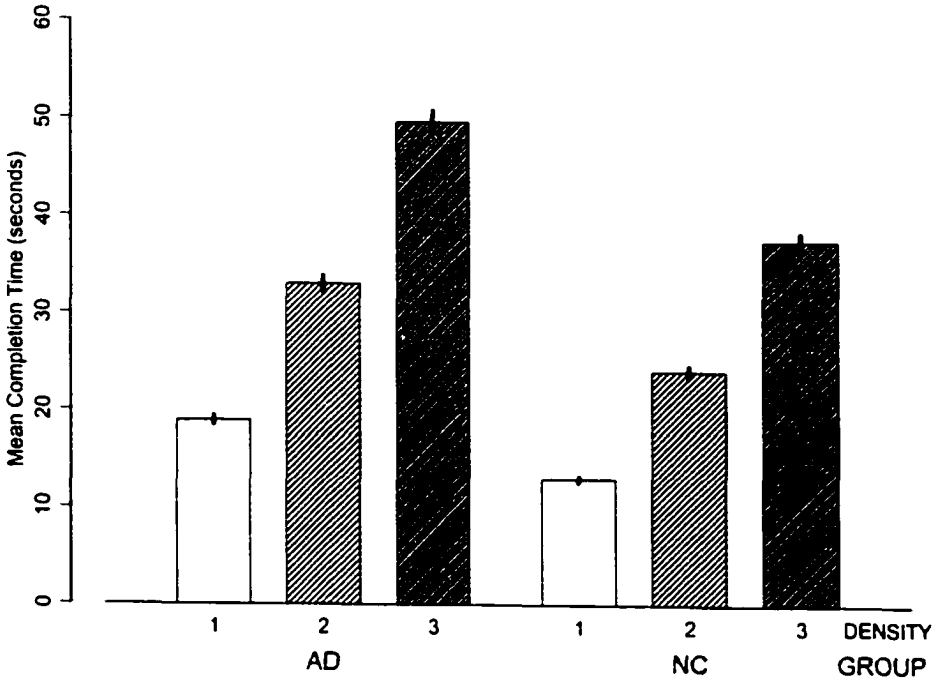


Figure 39. Expt 2, Mean Completion Time (seconds): Group x Density (p=.12)

(NC = Normal controls; AD = Alzheimer's disease)

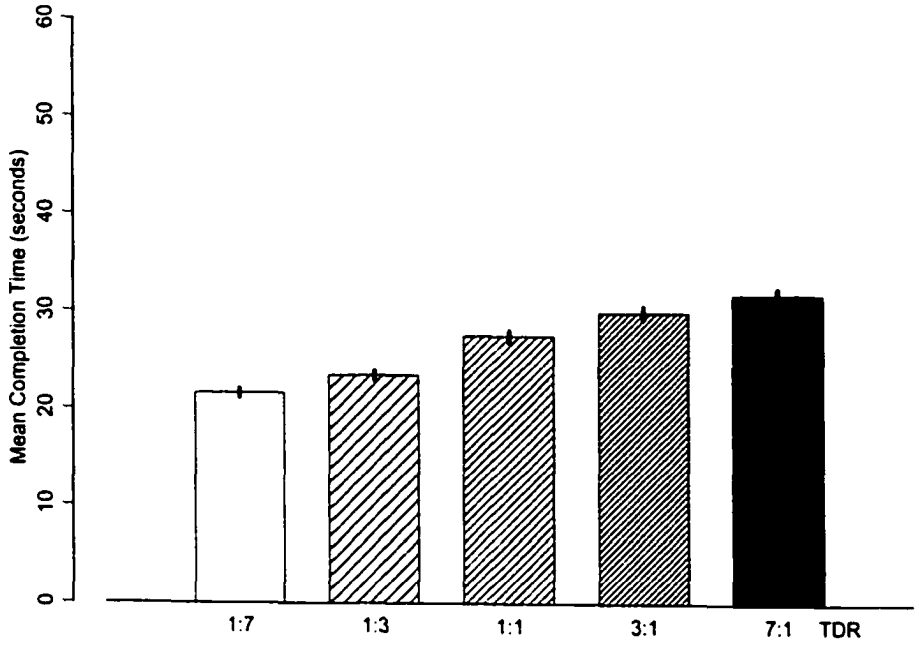


Figure 40. Expt 2, Mean Completion Time (seconds): TDR ($p<.00001$)

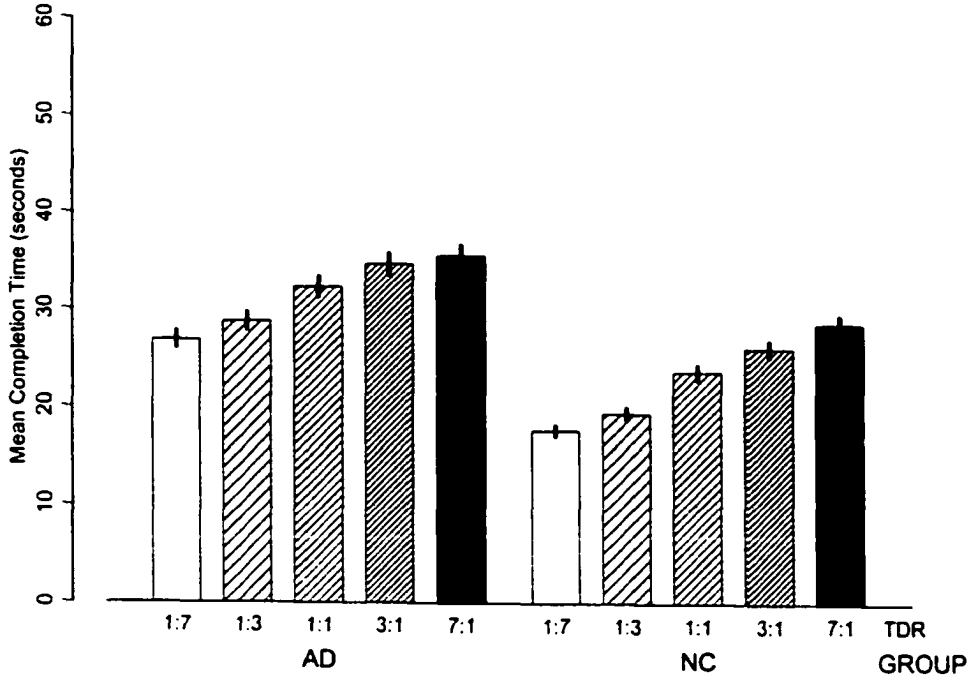


Figure 41. Expt 2, Mean Completion Time (seconds): Group x TDR (p=.008)

(NC = Normal controls; AD = Alzheimer's disease)

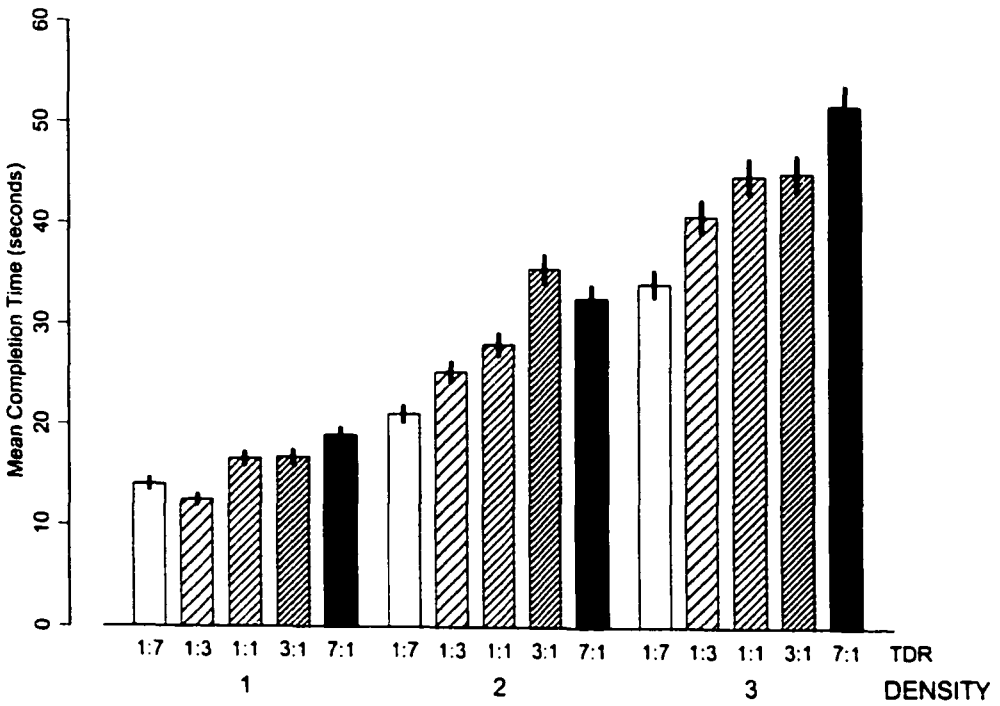


Figure 42. Expt 2, Mean Completion Time (seconds): Density x TDR ($p<.00001$)

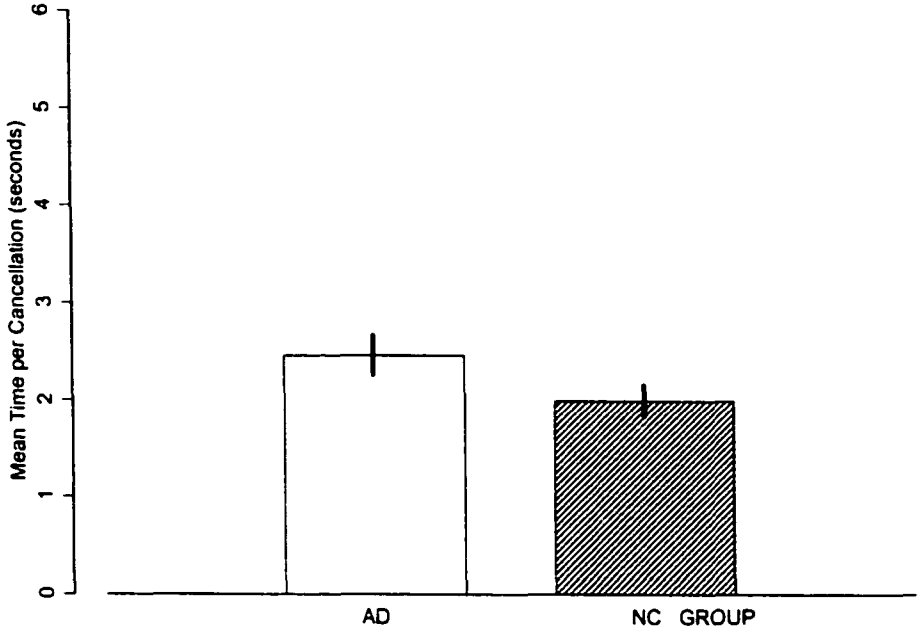


Figure 43. Expt 2, Mean Time per Cancellation (seconds): Group (p=0.078)

(NC = Normal controls; AD = Alzheimer's disease)

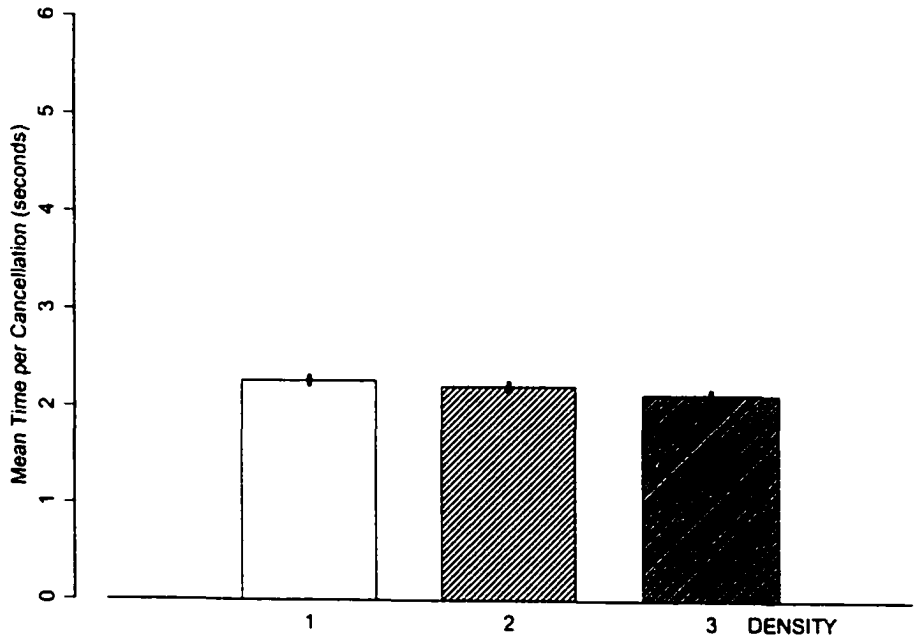


Figure 44. Expt 2, Mean Time per Cancellation (seconds): Density (p=0.11, n.s.)

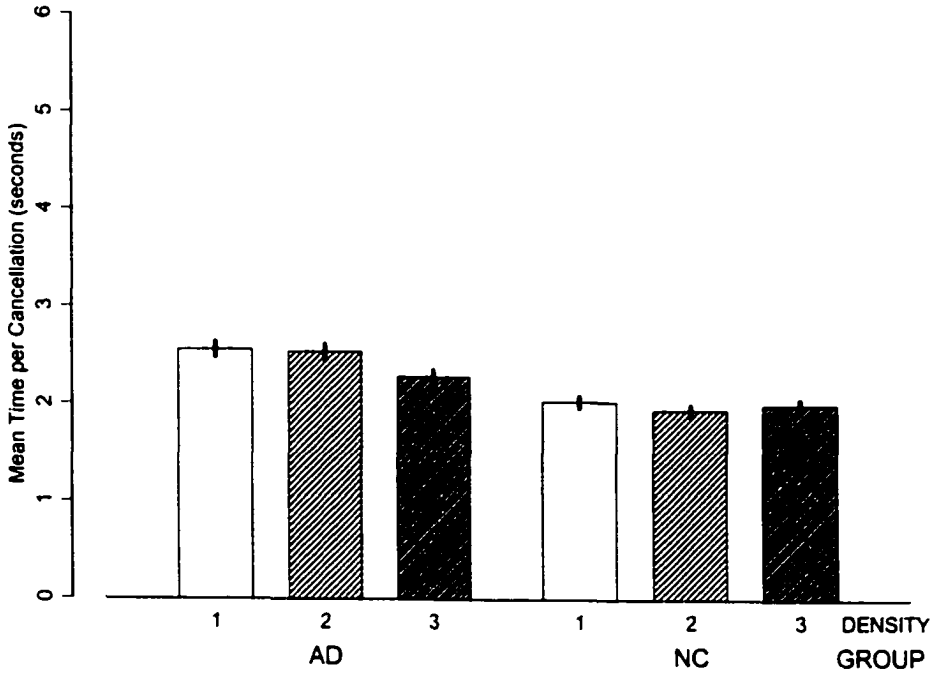


Figure 45. Expt 2, Mean Time per Cancellation (seconds): Group x Density (p=0.069, trend)

(NC = Normal controls; AD = Alzheimer's disease)

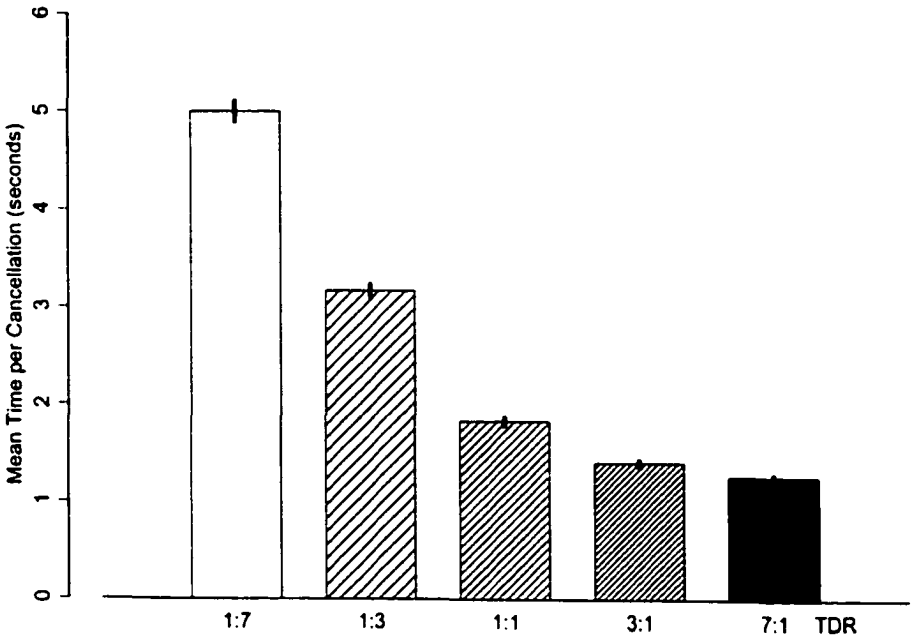


Figure 46. Expt 2, Mean Time per Cancellation (seconds): TDR ($p<0.0001$)

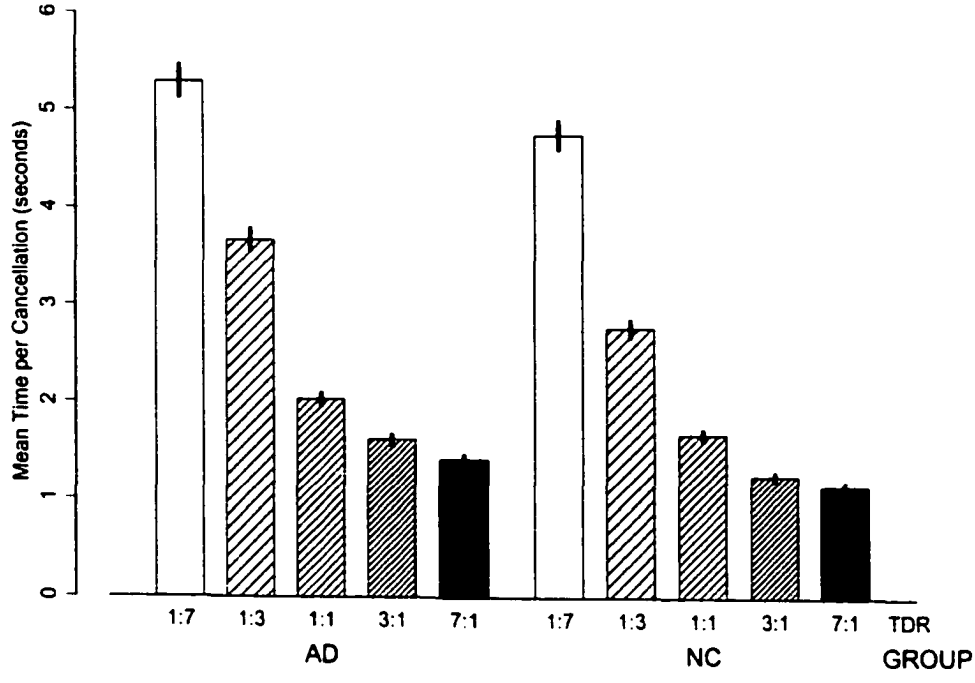


Figure 47. Expt 2, Mean Time per Cancellation (seconds): Group x TDR ($p = 0.19$, n.s.)

(NC = Normal controls; AD = Alzheimer's disease)

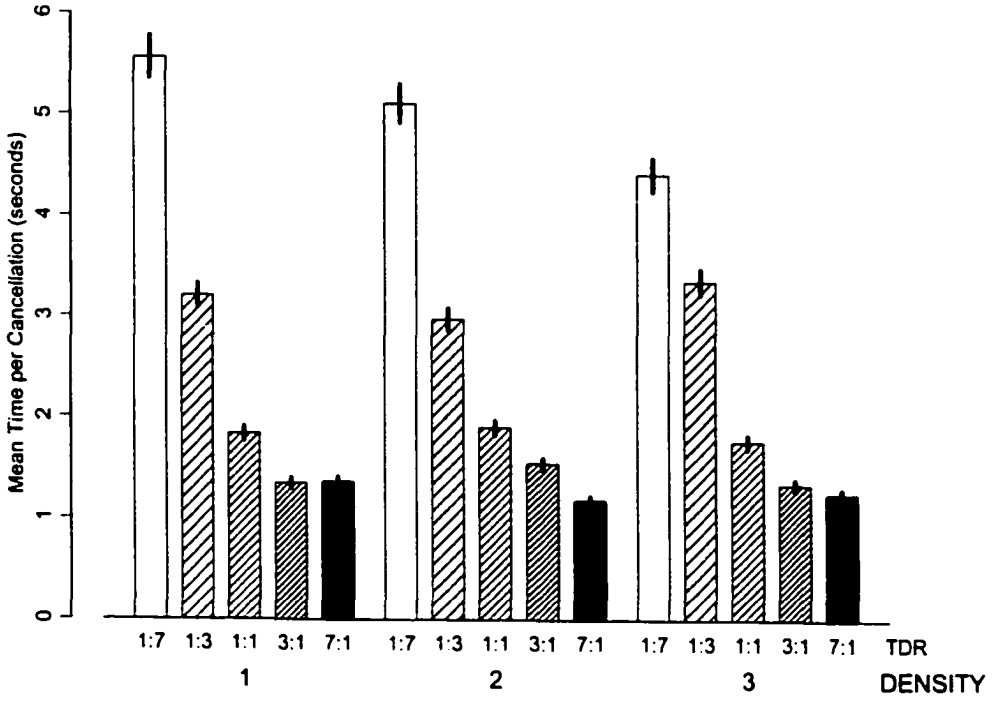


Figure 48. Expt 2, Mean Time per Cancellation (seconds): Density x TDR (p=0.005)

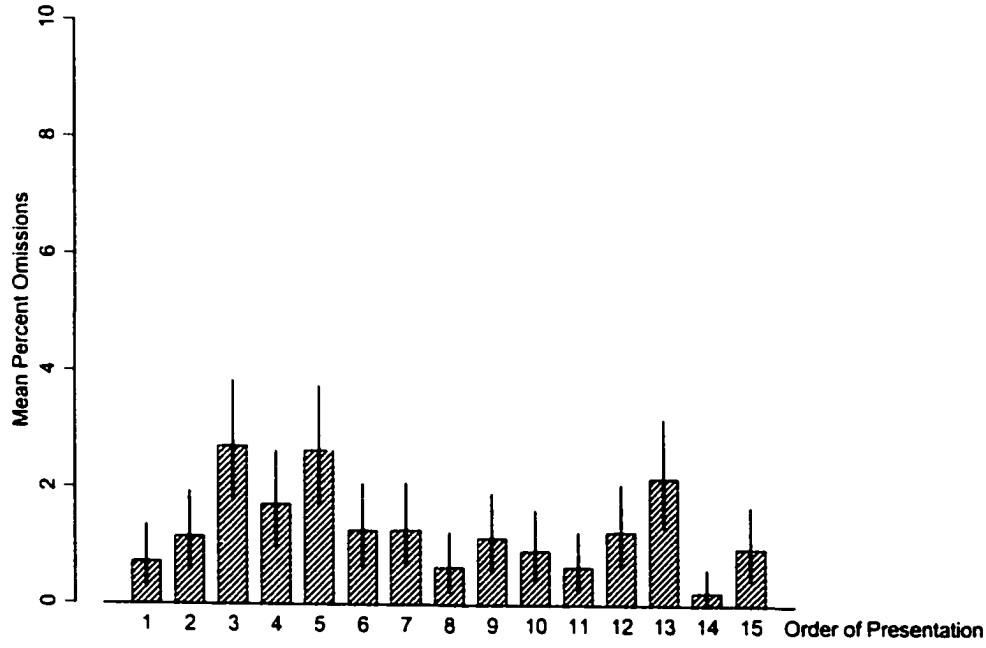


Figure 49. Expt 2, Order of Presentation, Mean % Omission Errors: Order ($p=0.42$, n.s.)

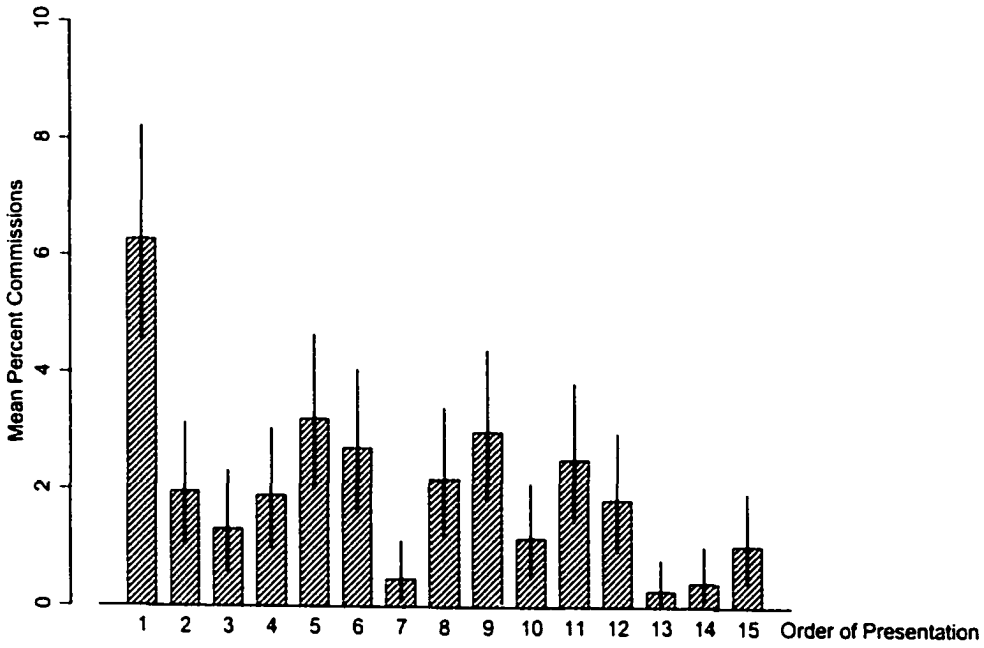
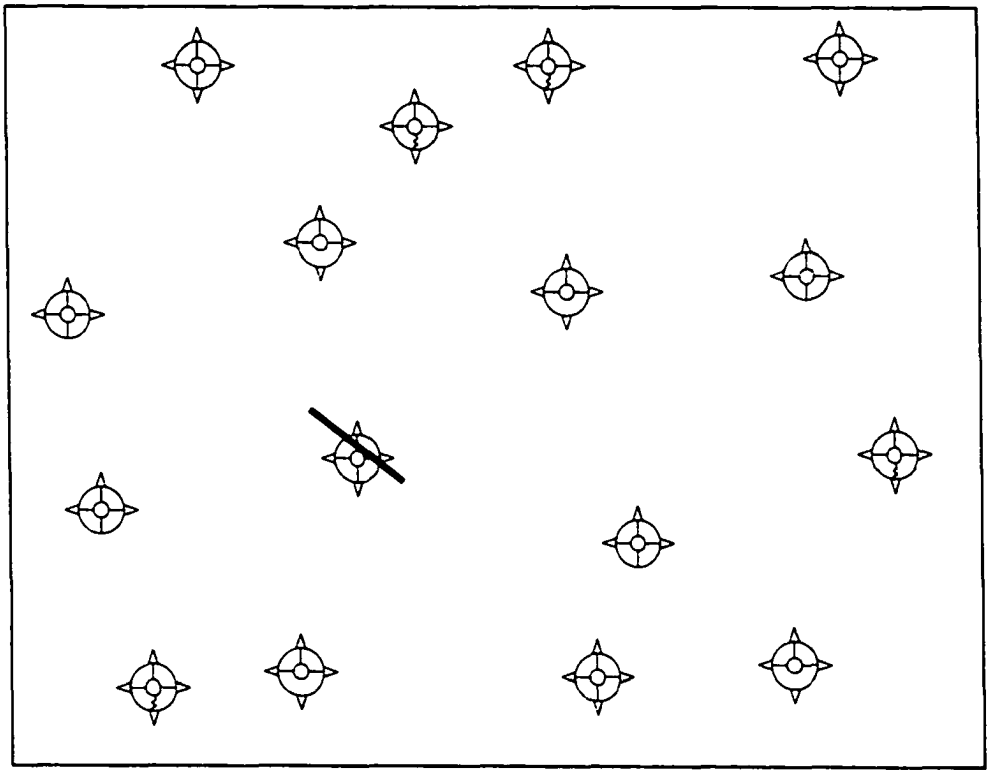


Figure 50. Expt 2, Order of Presentation, Mean %Commission Errors: Order (p=0.02)

APPENDIX A

Example of a single experimental cancellation test (reduced in size to show entire page). This cancellation test is part of Experiment 1 (Physical Similarity), with Physical Similarity = 1, Complexity = 3, and Density = 1. One of the 4 targets has been crossed out.



APPENDIX B

Pilot Study

Design

The goal of the pilot study was to choose the three sets of distractors, out of 11, that were to be used in the experimental study. Each set contained three drawings that varied from the target. The aim of the pilot was to choose the three sets of distractors that were as equivalent as possible along the dimensions of physical similarity and ordinal position. This was done by empirically determining the ordinal rank of each distractor within each set (e.g., which was the closest, next closest, and farthest away from the target), and then the physical distance between the target and each distractor within each set.

Participants

The pilot study was administered to 11 healthy older subjects, who were recruited from a pool of individuals at a senior-sponsored educational program. Subjects were called and screened to determine the subject's age and a gross determination of neurological and psychiatric history. Thirty-six people were called, of whom sixteen agreed to participate. Reasons given by the remaining twenty people for not participating included: the testing dates were not convenient, lack of interest, illness, and inability to drive to the site. Subjects who were chosen excluded those with a history of neurologic or psychiatric disease, alcohol or substance abuse, or ongoing treatment for any medical illness that could affect cognitive function (e.g., cardiac disease, hypothyroidism). Once

they met exclusion criteria and agreed to participate, subjects were tested to demonstrate that they did not have a dementia (Mini Mental Status Exam Score ≥ 26; Monsch et al., 1993). The subjects were asked beforehand if they were color-blind; none was. The subjects participated in the pilot study on a voluntary basis, and were unpaid.

Of the sixteen subjects originally chosen in the pilot study, five subjects were excluded for the following methodological and/or medical reasons. Data from three subjects had to eliminated because of errors in initial instructions and randomization procedures. Specifically, in order for subjects to fully understand their tasks, they needed two instead of one sample item. A fourth subject was excluded because he was found to have a diagnosis of Parkinson's disease. A fifth subject was excluded due to a transient ischemic attack (TIA). Of the eleven pilot participants, 64% were female and 36% were male. The average age of the subjects was 76.1 years. The subject's educational levels were not recorded.

Stimuli

The stimuli consisted of black line drawings, two centimeters square in size, that included the target and 33 distractors. The stimuli were generated on computer using Harvard Graphics 3.0 (Software Publishing Corporation, 1991-1994). All drawings were cut out and glued onto white cardboard squares, each two and a half inches square in size. In addition, two "sample" sets, each consisting of one new target and three distractors, were also designed, that were used to familiarize subjects with the procedure. The first sample used colored squares cut from origami paper - a red square was the target and the

distractors were a dark orange square, a lighter orange square, and a pale yellow square. The second sample was hand-drawn in black and white - this target was a square divided into four quadrants, none of which were filled in. The distractors had one, two, or three quadrants filled in. The target was always placed on a piece of black cardboard five inches square.

Part 2 of the pilot study (Physical distance between stimuli) involved the subjects placing the distractors on a numberless "ruler" where 7 divisions were indicated. The ruler was made of cardboard and was 21 inches long and two and a half inches wide. The ruler was white and divisions were indicated by one-quarter inch black strips of form board, which were glued to the cardboard at the ends of the ruler and at two-and-a-half inch intervals.

Procedure

Stimulus Randomization

Randomization of Set Number.

Set numbers were randomly determined by putting one identifying distractor from each set into a bag and selecting one at a time. The first distractor chosen became part of set I, the second distractor was set II, and so forth until all eleven sets were chosen. The set number was then written on the back of each card.

Randomization of Order of Set Presentation.

Each subject was presented with all eleven sets of distractors. A stepwise order of presentation was arranged, such that each order of presentation was represented once to

each subject. The sets were presented to the subjects in order, but the starting set varied by one for each subject. Thus, the first subject began with set I, and was then presented sets II-XI. The second subject began with set II, and was then presented sets III-XI, followed by set I, and so forth. Thus, order of presentation was counterbalanced.

Randomization of Order of Presentation of the Three Distractors.

Each time a given distractor set was presented, it was in the same order for each subject. This order was also randomized and was determined in the following manner. The three distractors were designated by the letters A, B, or C (depending on whether it was designed to be most similar to the target (A), least similar (C), or in between (B)) and the six possible combinations of three letters were assigned a number from 1-6 (ABC =1, ACB=2, BAC=3, BCA=4, CAB=5, CBA=6). Next, a die was rolled for each set to randomly determine the order that the cards would be presented. For example, if set I was determined to be presented as BAC, these were placed in front of the subject in that order from left to right. The order of presentation was printed on the back of the cards, for the use of the examiner. To avoid the possibility that the subjects would turn the cards over and use the presentation order (e.g., ABC), these letters were replaced with three-letter words. These three letters (i.e., SKI, RUB, MAN) were arbitrarily assigned to each set and were chosen because they spell words in only one order. This entire procedure was repeated for all eleven sets of distractors, as well as the two samples. The card presentation was modeled after the Picture Arrangement subtest of the Wechsler Adult Intelligence Test - Revised (WAIS-R; The Psychological Corporation, 1981).

Pilot Study Procedure

To Determine Order of Presentation.

The subjects were first given the two samples, followed by the eleven sets, and the same directions were given throughout. First, the target was placed to the subject's left. Three distractors from the same set were then presented, in the random order as described above. Subjects were told, "Please place these pictures next to the target, in the order that you feel they belong in relation to the target."

To Determine Physical Distance between Stimuli.

Again, the two samples were presented first, followed by the eleven sets, and the same directions were given throughout. The target stimulus was placed at the left end of the numberless "ruler" with its 7 divisions. Subjects were given the three distractors from each set, in the order that they had ranked them during Part 1 of the pilot study. The subject was asked, "Please put these pictures on the ruler, corresponding to where you feel they belong in relation to the target."

The place on the ruler was used as the measure of physical distance between the distractors and the target.

Scoring

For Part 1, the order that the subject placed the cards (indicated by the letters on the back upper right of the cards), the time it took the subject to complete each set, and any comments that the subject made were recorded. For Part 2, the examiner also recorded the number (1-7) corresponding to where the subject placed each of the three

distractors on the ruler, the time it took the subject to complete each set, and any comments that the subject made. If the subject changed their ordinal ranking of a set from Part 1 to Part 2, this was also noted on the score sheet.

Analysis and Results

The ordinal ranking of the distractors was analyzed using Kendall's Coefficient of Concordance (Ferguson, 1971). The outcome of this ranking was the most important criterion for selecting the three sets of distractors to be used in the experiment. This meant that there had to be the best agreement among subjects about the ordinal ranking of the distractors and a high coefficient value. Kendall's Coefficient of Concordance values were calculated for each set. Coefficients ≥ 0.9 were considered good agreement, and sets I, II, III, IV, V, IX, and XI met this criterion.

The next step in determining the three ultimate sets was to examine the data from the physical distance experiment (Part 2 of the Pilot study). Means and variances were calculated for each set, across all three positions. Since the desire was to have **three** sets with similar means, the outlying sets of set I and set XI were excluded for the following reason: Sets I and XI significantly correlated with each other ($r=.661$, $p=.037$) and with sets that are excluded by their low Kendall Coefficient (e.g. set I and set VII; and set XI and set X), but not with any other set. It was interesting to note that one of these two sets (set XI) was confusing to subjects; on two occasions, they switched their designated ordinal ranking of the distractors from Part 1 to Part 2 of the pilot. To further insure that

sets I and XI were outliers at all positions, the means and variances were then calculated for the 11 sets at each position.

At each of the three positions, separate 11 x 11 (set x subject) repeated-measures ANOVAs were performed. Results showed that the sets were significantly different at each position (Position 1: F= 2.247, p=0.021; Position 2: F=2.995, p=0.002; Position 3: F=2.705; p=0.006). Subsequent post-hoc correlations at each of the three positions determined which of the means were highly correlated. The sets that were highly correlated at all three positions were sets II, III, IV, and IX. These four sets can result in four separate groups of three (II-III-IV; II-III-IX; II-IV-IX; and III-IV-IX). Since our aim was to choose three sets, the highest correlations were found between sets II, IV, and IX (see Table 24). These three sets of distractors were therefore selected for the experiment.

Table 24: Pilot Study - Correlations Between Sets II, III, IV, & IX at Each of Three Positions. (Values given are Pearson R coefficients)

		set II	set III	set IV	set IX
set II	position 1		.263, n.s.	1.00 **	.671 *
	position 2		.365, n.s.	(.58)	(.532)
	position 3		.379, n.s.	.637 *	.871 **
set III	position 1			.263, n.s.	.033, n.s.
	position 2			.606 *	.013, n.s.
	position 3			(.592)	.391, n.s.
set IV	position 1				.671 *
	position 2				.283, n.s.
	position 3				.626 *
set IX	position 1				
	position 2				
	position 3				

** = $p < .000$
* = $p < .05$
( ) = $p < .1$

Limitations of the Pilot Study

A limitation of this pilot study was the small number of subjects (N=11) that was used. Ideally, it would have been beneficial to have at least two subjects for every order of set presentation. However, since all eleven orders of set presentation were represented

at least once in the present study, it is assumed that the results would have been similar even with a larger N.

APPENDIX C

INFORMED CONSENT

1. SUMMARY OF THE RESEARCH: The purpose of this research is to learn more about cognitive function in patients with Alzheimer's Disease to further our understanding of cognitive processes in healthy aging. As in all such research, patients with the disease are compared to persons who are optimally healthy and do not have any cognitive problems.

I understand that I will be asked to perform paper and pencil tests with an examiner in the neuropsychology office at Winthrop-University Hospital. The testing will last approximately two hours, which can be split into two sessions. I can take several breaks during the evaluation period and am also free to interrupt the examiner at any time. The tasks that will be administered will review an individual's memory, ability to use language, as well as visuo-spatial skills. The majority of these tests are currently used in standard evaluations of persons with cognitive difficulties. Several new tasks which are experimental will be included and are being developed during this research.

2. RISKS: There are no foreseeable risks in participating in this research. I am free to interrupt the testing if there is any discomfort whatsoever.

3. BENEFITS:
As is true of all neuropsychological procedures, these tests will not result in an improvement of my condition. I can receive personal satisfaction from the knowledge that my participation in this project has contributed to the advancement of science.
4. DISCLOSURE: Upon completion of the evaluation, I can request results of findings. I am aware that some neuropsychological tasks do not necessarily have 'right or wrong' answers and that results have to be interpreted by the evaluator.

5. CONFIDENTIALITY: I understand that results will be kept strictly confidential and that a subject's name does not appear on any study material.

6. PHYSICAL RISK: The cognitive tests are presented as question and answer or paper and pencil tasks. There is no physical risk anticipated. There is no provision made for me to

receive compensation or medical treatment at the psychologist's, physician's or hospital's expense for physical harm suffered by myself as a result of this procedure.

7. CONTACT: I understand that if I have any questions about the research, I may contact Dr. Nancy S. Foldi at (516)663-4525.

8. PARTICIPATION:

(a) I understand that participation in this research is voluntary. Refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. As a participant, I may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

(b) Strict criteria are being used to create matched groups of healthy controls with the patients with Alzheimer's Disease. It therefore may arise that the investigator chooses to terminate participation of the subject, without regard to subject's consent.

(c) Approximately 40 persons will be involved in the all stages of this research.

(d) No additional costs are foreseen from participation of the research. Participants will be responsible for transportation to and from the site of testing.

9. HUMAN RIGHTS STATEMENT:

If I have any questions regarding this procedure, I can contact Dr. Nancy S. Foldi (516) 663-4525.

I further understand that should I have any questions about my treatment or any other matter relative to my participation in this project, I may call the Institutional Review Board at Winthrop-University Hospital at (516) 663-2552 and I will be given the opportunity to discuss in confidence any question with a member of the Institutional Review Board. This committee, as required by Federal regulations and New York State law, is an independent committee composed of Winthrop-University Hospital physicians and staff as well as lay members of the community not affiliated with this institution.

Nothing in this informed consent is intended to limit the authority of a psychologist or physician to provide emergency medical care to the extent the psychologist or physician is permitted to do so under applicable Federal, State or Local Law.

10. I understand that I am free to withdraw my consent and discontinue participation from this study at any time without prejudice to me. I have read this consent form comprising 3 (three) pages and have received a copy of the same.

Participant's Name (please print)

Participant's Signature Date

Responsible Party or Legal Guardian's Name (please print)

Responsible Party or Legal Guardian's Signature Date

I, the undersigned, herewith affirm that I, or one of my associates, has explained the above to (Mr.) (Ms.) _____and I am willing to answer any further inquiries.

Nancy S. Foldi, Ph.D. Date

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