ABSTRACT

Title of dissertation: AGING, ILLUSORY CONJUNCTIONS, AND ATTENTION

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Elderly adults do not perform as well as young adults on complex tasks. Elderly adults' poorer performance may be partly due to an age-related increase in the occurrence of illusory conjunctions. To investigate this possibility, this research is designed to examine the relationship between attention and illusory conjunctions in young and old adult performance. Experiment 1 is modeled after Cohen and Ivry (1989; Experiment 3) and requires participants to perform concurrent digit-matching and letter identification tasks. The digit-matching task manipulates the spread of attention, i.e., narrow vs. wide; and the letter identification task provides opportunity for illusory conjunctions, because both a target and non-target letter differing in color and identity appear in the display. The results suggest that selective attention affects the formation of illusory conjunctions in young but not elderly adults. In young adults illusory conjunctions are more likely to be formed within the attentional window. The

elderly are just as likely to form illusory conjunctions inside and outside the attentional window.

Because the design of Experiment 1 requires the participants to identify two properties of the target letter simultaneously (i.e., the subject must determine the color and the shape of the target letter) this experiment is a dual property experiment. Since elderly performance often suffers when required to complete simultaneous tasks (Craik, 1977; Hartley, 1992; McDowd & Shaw, 2000), it is possible that an age-difference in the occurrence of illusory conjunctions in Experiment 1 was due to age differences in ability to handle dual task performance. Experiment 2 was used to investigate this possibility. Thus, Experiment 2 consisted of two conditions. In the dual property condition, the participants were required to determine both the color and the identity of the target letter. In the single property condition, the subject only reported the color of the target letter. Experiment 2 demonstrated that the results of Experiment 1 were not due to the dual property nature of Experiment 1. The pattern of illusory conjunctions was similar whether the requirements of the task were to identify one or two properties of the target letter.

AGING, ILLUSORY CONJUNCTIONS, AND ATTENTION

by

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CHAPTER 1: INTRODUCTION

Older adult performance on complex visual search tasks is often worse than young adult performance (Hartley, 1992; McDowd & Shaw, 2000; Salthouse, 1991). The mechanisms underlying this phenomenon are not well understood. The study of age differences in the prevalence of illusory conjunctions may reveal some of the contributory mechanisms. The role of attention is also examined as attention may be integral in the formation of illusory conjunctions and attention is associated with deficits in elderly performance (Hartley, 1992; McDowd & Shaw, 2000).

Although a more formal definition, based on Treisman and Gelades' (1980) Feature Integration Theory, is provided below, suffice it to say that an illusory conjunction occurs when two features are erroneously conjoined to form an object. For example, an individual may inadvertently combine the feature "green" of a bicyclist's jacket with the feature "O" of a traffic light, thereby perceiving a green light when the light is actually red. Young adult data on illusory conjunctions suggest the stimulus conditions that produce illusory conjunctions.

Studies examining young adult performance suggest that susceptibility to illusory conjunctions increases when the target and distractor are spatially adjacent to each other (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Cohen & Ivry, 1989; Hazeltine, Prinzmetal, & Elliot, 1997, Ivry & Prinzmetal, 1991), when the target and distractor have similar features (Ivry & Prinzmetal, 1991), when the features that are conjoined are from the same perceptual group (Lasaga & Hecht, 1991; Prinzmetal & Keysar, 1989), and are presented closely in time (Botella, Garcia, & Barriopedo, 1992;

Intraub, 1989; Keele, Cohen, Ivry, Liotti, & Yee, 1988). In each of these stimulus conditions, features of the target and distractors are likely to be confused. In the studies reported in this dissertation the role of attention is examined by looking at stimulus conditions that differ in their attentional demands; and also by contrasting younger and older adults, who might be thought to differ in their attentional capacity. It is hypothesized that illusory conjunctions will be more prevalent in older adults under demanding attentional conditions. In addition, a statistical methodology will be employed that may help specify the processes that contribute to errors in attentional processing.

Attentional Theory and Illusory Conjunction

There has been considerable research on the role of attention in the production of illusory conjunctions in young adults. This research has been prompted by two-stage theories of object perception. These theories have driven empirical research for over two decades (Feature Integration Theory; Guided Search; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 1994, 1998; Wolfe, Cave, & Franzel, 1989; Wolfe, Klempen, & Dahlen, 2000). According to these theories perceptual processing occurs in two stages: (1) an early feature detection stage, and (2) a late feature combination stage. The early theory, Feature Integration Theory, (Treisman, Sykes, & Gelade, 1977; Treisman & Gelade, 1980; see Quinlan, 2003 for a review of Feature Integration Theory) posits that in the first (non-attentional stage) features are free-floating. Only in the second attentional stage are features combined into objects. An erroneous combination of features into objects presumably results when free-floating features are inadvertently combined.

More recent research has demonstrated that a number of predictions concerning illusory conjunctions of the earlier two-stage theories do not always hold true because a free floating features model assumes that the features that are erroneously combined are combined at random. Evidence suggests that illusory conjunctions do not occur randomly -- as described by Treisman -- but as the result of guesses based on the location of the search object (Cohen & Ivry, 1989; Ashby, Prinzmetal, Ivry, & Maddox, 1996; Hazeltine, Prinzmetal, & Elliot 1997). That is, the search is perceptually guided. For example, suppose a subject searched for a target (a red "X") in a display consisting of two non-targets (a green "X" and a red "O"), and all the features were perceived, but not in the correct location. Then the perceptual system, in an effort to determine how the features combine, might use a simple decision rule. It might combine the features located closest to each other (for example, combine the shape "X" with the color red to erroneously perceive the illusory conjunction, a red "X"), and report that the target was present when it was not. Multinomial modeling was used to compare models that describe the occurrence of illusory conjunctions. When a random binding model (a free floating features model) was compared with a location uncertainty model (illusory conjunctions tend to form between features in close proximity), the location uncertainty model provided a better fit for the data (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Prinzmetal, Ivry, Beck, & Shimizu 2002).

Additional research on the spatial location of perceived illusory conjunctions suggests that perceived illusory conjunctions are not equally dispersed throughout the spotlight of attention -- as predicted by Feature Integration Theory -- but that the location of illusory conjunctions can be somewhat predicted by the location of the constituent features (Hazeltine, Prinzmetal, & Elliot 1997). That is, the location of illusory conjunctions tends to be midway between the location of the target and the location of the distractor. Hence, features are not 'free floating' within the spotlight of attention because the perceived location of illusory conjunctions is related to the actual location of the constituent features.

There is also some evidence that suggests that illusory conjunctions are observed regardless of whether attention is diverted or not (Treisman & Schmidt, 1982). Prinzmetal et al. (Prinzmetal, Henderson, & Ivry, 1995) employed an attention-diverting task and found that it did not affect incidence of illusory conjunctions. Attention was diverted by visually presenting digits at fixation and requiring the participant to respond every time a “0” appeared. Thus attention did not seem to be an essential component in producing illusory conjunctions.

Reformulation of Feature Integration Theory and new theories describing feature integration were prompted by the above findings and other research (for a recent review see Quinlan, 2003). Recent theories of feature integration suggest that the role of attention in visual search is more complicated than first proposed by Treisman and Gelade (1980). Each of the theories defines the role of attention and its place in processing differently. Treisman and Sato (1990) suggested that top-down attentional processes are used to eliminate (lessen activation) certain nontarget items from visual search. Wolf (1998; 1994) proposed a model similar to Treisman and Sato (called the Guided Search Model) in which top-down attentional processes are used to increase activation of target items. That is, serial search is guided by two processes: (1) a comparison of the features in the first search (a bottom-up process) and (2) a map of what the participant is searching for (a top-down process). Thus, if a participant is searching for a red “X”, he/she has a map of red items and a map of X shaped items that guide the search to that particular location. And Duncan and Humphreys (1989) proposed the Attentional Engagement Theory where the first stage of visual processing is governed by the perceptual similarity of the targets and the distractors and the similarity of the non-targets. In the second limited capacity (attentional) stage the information that is passed on from the first stage is acted on.

Briand and Klein (1987) compared Posner's concept of attention (Posner uses a beam as an analogy of how attention operates) to Treisman's concept of attention (the "glue" that binds together separate features). Briand and Klein (1987) suggest that there is a difference between endogenous orienting (visual cue is centrally located) and exogenous orienting (the visual cue appears in the periphery). Differential attentional effects of feature vs. conjunction search appear with exogenous orienting but not endogenous orienting. Thus, Briand and Klein might predict illusory conjunctions with exogenous orienting (when attention is controlled by a central process) but not with endogenous orienting (when attention is controlled at a perceptual level).

In the present experiment, support for a Feature Integration Theory explanation of illusory conjunctions will be evident if illusory conjunctions are more prevalent between items that are located within than between items located outside of the attentional window (Treisman & Gelade, 1980; Treisman & Schmidt, 1982). Further support of Feature Integration Theory will be found if there is no location effect in the incidence of illusory conjunctions. Support for the location uncertainty theory explanation will be found if, in the present experiment, the frequency of illusory conjunctions increases as the distance between the target and the distractor increases.

Aging and Attention

There is considerable research in the aging literature devoted to the effects of attention on elderly adult performance (McDowd & Shaw, 2000; Hartley, 1992; Salthouse, 1991). Attention is a multidimensional construct. In this dissertation, the focus is on two functionally different dimensions of attention: selectivity and divided attention (see McDowd & Shaw, 2000 for a functional analysis of attention). Selective attention is the ability to select some stimuli and ignore other stimuli. Divided attention is the ability to divide attention between two or more tasks. In Experiment 1 of this dissertation the effects of selective attention on aging and illusory conjunctions is examined. In Experiment 2 the effects of divided attention on aging and illusory conjunctions is examined.

Selective Attention and Aging

Selective attention is the ability to attend to some stimuli and ignore other stimuli. Most selective attention experiments require participants to do a task that requires attending to a target and ignoring distractors. Rabbitt in 1965 was the first to do this type of experiment with the elderly. Rabbitt found that in a search of a target among a field of a varying number of distractors that there was an age difference in performance, and the age difference increased as the number of distractors increased. That is, there is a greater cost to elderly performance the greater the selective attention demands of an experiment. A review of the selective attention and aging literature goes beyond the scope of this paper (see McDowd & Shaw, 2000; Hartley, 1992; Salthouse, 1991). The following section, on aging and illusory conjunctions, includes a sample of selective attention experiments that compare age differences and that suggest that performance may be influenced by the formation of illusory conjunctions.

Aging and Illusory Conjunctions

Older adults do not perform as well as young adults in search tasks under conditions in which it is possible to perceive illusory conjunctions. Studies that systematically vary the featural relationship between the targets and the distractors have provided the most direct evidence for an increase in age-related illusory conjunctions (Burton-Danner, 2001; Plude & Doussard-Roosevelt, 1989; Humphrey & Kramer, 1997; Madden, Pierce, & Allen, 1996; Scialfa, Esau, & Joffe, 1998). For example Plude and Doussard-Roosevelt (1989) used a visual search task to compare feature and conjunction search by young and old adults. In the negative probe (i.e., target absent) feature condition --where the non-targets differ from the targets in both color and form and illusory conjunctions are not possible -- older adults and young adults exhibited comparable error rates. In the negative probe conjunction condition --

where the non-targets either shared color or form with the target and illusory conjunctions are possible -- older adults had a higher error rate than younger adults. Thus, when performance requires the conjunction of features, older adults do not perform as well as young adults. It is possible that this is partly due to an age-related increase in illusory conjunctions.

Additional evidence that the elderly may be more susceptible to illusory conjunctions is found while examining elderly adults' performance in conjunction search. Elderly adult performance is compromised when the distractors are highly similar in conjunction search (Scialfa, Esau & Joffe, 1998). Since illusory conjunctions are formed more frequently when the distractors are similar (Duncan & Humphreys, 1989), it is possible that this indicates that the elderly are more susceptible to illusory conjunctions. And when the extra demands of a conjunction search are reduced, older adults benefit as much as younger adults. For example, in triple conjunction searches (three features define the target) older adult performance is assisted to the same extent that young adult performance is improved (Humphrey & Kramer, 1997).

Older adult performance is preserved in some studies that decrease the chances of illusory conjunctions. Evidence from visual marking tasks suggest that elderly adult performance on certain visual search tasks is preserved. Visual marking tasks examine inhibition by marking items in a visual field (Watson & Humphreys, 1997; Kramer & Atchley, 2000). Watson and Humphreys (1997) used a task where they compared performance on feature search (blue H, in a field of green "H"s), conjunction search (a blue H in a field of green "H"s and red "A"s) with a condition they called a preview condition (the preview condition is sometimes referred to as the gap condition). The preview condition is similar to a conjunction search but half of the distractors are displayed before the target is presented, and the distractors remain in the display for the duration of the trial. This task is used to demonstrate that if the subject performs on the gap task as he/she did on the feature search, then the subject was able to inhibit search of the cued distractors. Visual marking is demonstrated by both young and elderly adults. This suggests visual marking is preserved in elderly performance. However, there is some evidence that this is only the case with stationary objects and that there is some age deficit with moving objects (Watson & Maylor, 2002).

In many complex visual search tasks an increase in illusory conjunctions may not directly result in an increase in total error rate (ER). Total error rate is a measure of both false alarms (when the participant responds that there is a target present when the target is absent) and misses (when a target is present but the subject responds that is absent). An age-related increase in illusory conjunctions would suggest that older adults respond with more false alarms and fewer misses than the younger adult, resulting in an overall ER that shows no net age differences. Because the results of complex visual search tasks are often that the older adult has a higher ER than the younger adult, perhaps the effect of illusory conjunctions on older adults' performance is more complicated. Perhaps the older adults' performance can be explained by an increase in the older adults' cautiousness when identifying a target (given their increased susceptibility to illusory conjunctions). If the older adult tends to check and recheck before responding, then the increase in reaction time (RT) may result in a loss of information and a concurrent increase in ER. This results in the more traditional pattern of age differences found in complex visual search tasks.

In conclusion, although elderly adults' performance is often compromised in visual search tasks that require selective attention, the mechanism behind this phenomenon is not known. However, elderly performance is often affected when a conjunction search is required and illusory conjunctions are possible in conjunction searches. A number of different lines of research suggest that it is possible that illusory conjunctions may be partly responsible for this phenomenon.

In Experiment 1 of this dissertation the effects of varying selective attention on the formation of illusory conjunctions in the young and older adults is examined. The attentional window is adjusted and the incidence of illusory conjunction formation inside and outside the attentional window is measured. If the attentional window is successfully adjusted then display items inside the attentional window are selected and display items that fall outside the attentional window are ignored.

Divided attention and aging

Historically, one of the most consistent findings in the aging literature is that there is age-related interference associated with dual tasks. Craik in 1977 summarized the findings of the dual-processing experiments and found, "One of the clearest results in the experimental psychology of aging is the finding that older subjects are more penalized when they must divide their attention either between two input sources, input and holding, or holding and responding" (p.391). More recently Kramer and Larish (1996) agreed with Craik's earlier assessment, "One of the best exemplars of a mental activity in which large and robust age-related differences have been consistently obtained is dual-task processing." (p. 83). Hartley (1992) also finds support for this finding and he argues that it stands up using many methodologies (also see Chen, 2000). McDowd and Shaw (2000) also agree that dividing attention between "two or more sources of information" usually affects older adults more than younger ones.

Although most agree (not all, see Salthouse, 1991) with the finding that the elderly do not perform as well as young adults in dual task paradigms, there is disagreement over why this is the case. One view is that it is not that the elderly have more difficulty with dual-tasks *per se*, it is that older adults do not perform as well on any task that is more complex (Salthouse, 1991; McDowd & Craik, 1988; among others). And certainly a dual task is more complex. This view is often called the complexity hypothesis. Support for this view is found in studies demonstrating that the elderly do not show a decrease performance in dual tasks when the tasks are very simple (Somberg & Salthouse, 1982). However, if there are more operations to be completed in a certain task (as there are in dual tasks) there will be a concomitant interference in task performance associated with age. Another view is that age-related dual-processing interference is the result of generalized slowing associated with aging (Cerella, 1990; Fisk, Fisher, & Rogers, 1992; Myerson, Hale, Wagstaff, & Poon, 1990; Cerella, & Hale, 1994). This view posits that all cognitive operations slow with age. A third view is that the elderly show interference in dual-task processing because the elderly have limited cognitive attentional resources (Tsang & Shaner, 1998; Plude & Doussard-Roosevelt, 1989) and dual-tasks often require more or different attentional resources to complete. The present experiment is not designed to disentangle the underlying reason (or reasons) for dual-task interference for the elderly, but the results will be discussed in light of the above hypotheses.

In Experiment 2, the dual property task used in Experiment 1 is compared to a single property task (the identification solely of the color of the target). A similar experiment was conducted by Bonnel and Prinzmetal (1998) that examined younger adults' dual-task interference. In the relevant condition, dual-task interference was examined in a task where the participant was required to identify either the color (blue or green) or the color and the shape (T or F) of a target letter. Performance was comparable (no difference in accuracy) in the single and dual tasks. This experiment is designed to validate the prior finding but under conditions that enable isolation of the role of illusory conjunctions.

There is some question as to which operation (or operations) in the dual-task paradigm is affected by the dual-nature of the task in the elderly. Some evidence suggests that age differences are present in both encoding and retrieval (Anderson & Craik, 1998; Hartley & Little, 1999). Hartley (2001) compared young and elderly performance on two simple, well-practiced dual-tasks, where the onset of each task was carefully controlled. The participants were required to signal a color change in a target letter, then subsequently signal the identity of a letter that replaced the target letter. The stimulus-onset-asynchrony (SOA) was varied so that sometimes the first task was completed before the second task began, while at other times the two tasks were completed concurrently. This arrangement enabled Hartley to examine dual-task interference at input and at response. Hartley found age differences in dual-task interference only at response. This observation is in concordance with recent dual-task interference studies in young adults. For example, Pashler (1998) argues that the "bottleneck" in attentional processing occurs at the point of generation of the response. The present experiment examines interference during response.

In conclusion, in Experiment 2, a comparison of single and dual property tasks is warranted given that examples of age differences in complex dual-tasks are abundant in the literature.

Description of Experiment 1

Experiment 1 in the current research was modeled after Cohen and Ivry (1989) to determine if there is an age-associated increase in illusory conjunctions and if these errors vary across selective attention conditions. The task set the participant consists of two components: reporting the match between two digits, and identifying the color and shape of a target letter. The digit matching/mismatch task is used to manipulate the span of attention. The two digits appear in a linear display that contains six possible target letter positions. The digits enclose two or four target/distractor positions (see Figure 1). When two target/distractor positions are enclosed, then the participant's attention is focused in a narrow spotlight. And when four positions are enclosed the attentional window widens to include the additional target/distractor positions. In addition, the features of a target and a distractor are manipulated to allow erroneous combinations of features into illusory conjunctions. Figure 1 shows the possible positions of the target and the distractor in the narrow and wide spotlight conditions. One target and one distractor appear in each trial, the target on one side of fixation and the distractor on the other. Three different target/distractor pair locations are tested; AF, BE, and CD where CD is the most central pair and AF the most peripheral (see Figure 1). Participants respond by making three decisions, (1) a digit match/nonmatch, (2) target character, (3) target color. Each of the participants'

In the narrow spotlight condition:

A B __ C + D __ E F

In the wide spotlight condition:

A __ B C + D E __ F

Figure 1. Example of the display. The letters represent the six possible positions of the target letter and distractor in the display. The possible location of the digits is marked by a "____". Notice that in the narrow attentional condition only C and D fall within the attentional spotlight. In the wide spotlight condition positions B, C, D, and E, fall within the attentional window.

responses are indicated by pressing a labeled key on a keyboard. Hence a direct measure of illusory conjunctions (and all other types of errors) is possible. The number of errors at each location and attentional window size is recorded. It is expected that older adults will be more susceptible than young adults to illusory conjunctions. Multinomial analysis will be used to determine if illusory conjunctions are entirely due to guessing. There is sufficient evidence that illusory conjunctions do occur, and the current research focuses on examining age differences in this phenomenon.

Hypotheses

1. Consistent with Cohen and Ivry (1989; Experiment 3), young adults will exhibit more illusory conjunctions inside compared to outside the attentional window. Therefore, susceptibility to illusory conjunction will vary depending on the position of the target and the distractor. In both attention conditions the CD pair falls within the attentional window, thus the number of illusory conjunctions at this position (see Figure 1) will be high in both attention conditions. The BE pair position falls outside the attentional window in the narrow attention condition, and inside the window in the wide attention condition. Thus the number of illusory conjunctions will be high in the BE position in the wide attention condition and low in the narrow. The AF position always falls outside the attentional window; susceptibility to illusory conjunctions will be low in both attention conditions.

2. Consistent with Cohen and Ivry (1989), when both the target and the distractor fall within the field of attention the distance between the target and the

distractor will not affect susceptibility to illusory conjunctions. Consequently, the number of illusory conjunctions at each pair position within the attentional window will be similar. That is, in the wide attention condition, susceptibility to illusory conjunctions will be comparable at the CD and BE pair positions.

3. Elderly adults will be more susceptible to illusory conjunctions than younger adults. Whether the number of illusory conjunctions is greater within or outside of the attentional window is an empirical question. If there is a difference in the number of illusory conjunctions inside and outside the span of attention, then selective attention deployment affects the number of these errors. If, however, there is no difference in the number of illusory conjunction inside and outside the span of attention then attention does not affect the number of illusory conjunctions.

CHAPTER 2: EXPERIMENT 1

Methods

Participants

There were two groups of participants, 35 young and 34 elderly adults. The mean age of the young adults was 20.2 years (*SD* = 3.3, range = 17-33 years). The mean age of the older adults was 74.0 years (*SD* = 6.3; range = 50-89 years). The young adults were recruited from introductory psychology classes at the University of Maryland and received course credit in exchange for their participation. Independently living elderly adults were recruited from community centers and student programs around the University of Maryland, Drake University, and Delaware, Ohio. The older adults received $5.00 for participating in this experiment. The two groups differed in years of education and performance on two WAIS-R (Wechsler, 1981) subtests (vocabulary and digit-symbol). The elderly adults had completed more years of formal education (*M* = 16.5 years, *SD* = 2.2) than the young adults (*M* = 14.0 years, *SD* = 1.7), $t(97) = 6.29$, $p < .01$. The older adult scores on the vocabulary subscale were higher (*M* = 57.5, *SD* = 9.8) than the younger adults' scores (*M* = 48.1, *SD* = 10.2), $t(95) = 4.56$, $p <. 01$. Conversely, the younger adults scored higher on the digit-symbol subscale (*M* = 68.2, *SD* = 10.7) than the older adults (*M* = 46.8, *SD* = 12.0), $t(96) = 9.32$, $p <. 01$. The participants were screened for visual acuity using the Rosenbaum Pocket Vision Screener and all participants had vision of 20/30 or better. Participants were also screened for color vision using the Pseudo-Isochromatic Plate test and those exhibiting color blindness (any shape recognition errors on any of the screening plates) were excused from participation.

Design

Brief Description of Task

There are two tasks, a primary one, of determining whether two numbers are matched, and a secondary one of identifying the color and shape of a target letter when a distractor is shown (see Figure 2). The target letter lies on one side of a fixation point and the distractor equidistant but on the other side of the fixation point. The letter target and distractor can appear at 3 locations that vary in proximity from a fixation point, near (CD), middle (BE) and far (AF). The primary task is used to set up a spotlight of attention for the secondary task because the digits to be compared either bracket the near positions, CD (narrow spotlight) or the middle positions, BE (wide spotlight).

In the secondary task the location of a target and distractor were manipulated to allow for erroneous combination of features into illusory conjunctions. One target and one distractor appeared in a linear display, one on either side of a fixation point (see Figure 1). In addition, a digit match/mismatch task was used to manipulate the span of attention. The digits either enclose one or two target/distractor positions. When one target/distractor position is enclosed then the participant's attention is focused in a narrow spotlight. And when two target/distractor positions are enclosed the attentional window widens to include two target/distractor positions.

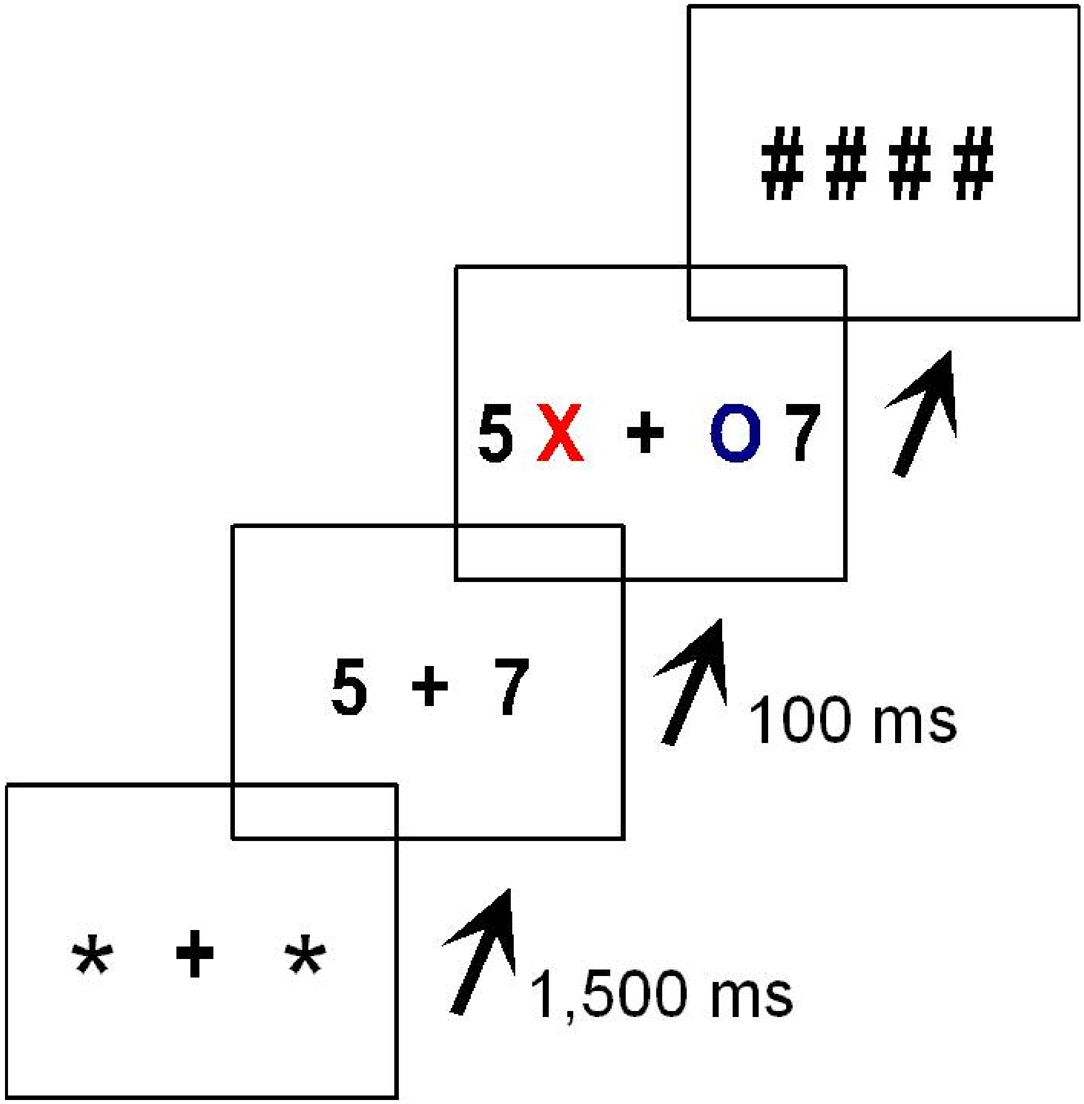


Figure 2. Description of the steps in each trial. First a display with a fixation point (a "+" sign) and two asterisks (the asterisks cue the location of the digits) is presented. After 1,500 ms the asterisks are replaced with two digits (the digit matching task is used to vary the size of the attention window). Then 100 ms later the target letter and a distractor are added to the screen. The display duration varies for each individual (see text) and then the entire display is masked with hash marks.

Target/Distractor Pair Location

There were three target/distractor pairs. One of the letters of the pair was a target letter, (for some of the participants the target letter was either a "F" or an "X" and for others the target letter could be any consonant except Q; see Appendix A for a comparison of these two variations) and the other letter was a non-target distractor (which was always an O). The target color was selected, without replacement, from a set of four colors (blue, green, red, or purple). The distractor color was also selected without replacement from the same set of four colors. The two letters appeared in any of six locations in the display (A-F; see Figure 1) which can be described with reference to a white fixation point (a +) which appeared in the middle of the display. One letter always appeared on the left side (A-C) and the other on the right side of the fixation point (D-E). The specific location pairs (working outward from the fixation point) were: C-D, B-E, and A-F.

Attention Conditions

There were two attention conditions in this experiment, narrow and wide. The size of the attentional window was manipulated using a digit match/mismatch task. In the narrow condition the digits spanned 3 degrees of visual angle and therefore enclosed locations C & D and in the wide condition the digits spanned 6 degrees and therefore also encompassed locations B and E. The digits appeared as white stimuli against a black background. Notice that the target/distractor pair B-E is located inside the attentional window in the wide condition and outside the attentional window in the narrow condition. This arrangement allows for a comparison of the effects of different attention conditions on the same target/distractor location pair.

There were six blocks of 32 trials each. In each block there were 16 trials at the diagnostic BE pair position, and 8 trials at each of the AF and CD pair positions. For each pair position half of the trials were presented with a narrow attentional window and half with a large attentional window.

Procedure

The participants were greeted, and asked to provide some background information on education, age, occupation, and health status. They were then seated before a computer display. The participants were instructed that the digit match/mismatch task is their primary task and to devote as much attention to it as needed to successfully complete the task. The participants were also informed that their secondary task was to determine the identity (a consonant) and the color (red, green, blue or purple) of the target letter (see Appendix 2 for specific instructions). The participants were informed that the display would only appear for a very brief period of time. Two asterisks and a plus sign would appear on the screen, they were to look at the middle plus sign and spread their attention to the asterisks. Participants were instructed that the asterisks would cue them as to the location of the digits so it "makes sense" to attend to the outer plus signs. They were also told that after the appearance of the digits a colored letter and a distractor (an "O") would appear. Once they had seen the display, they were to press the key labeled "match" on the keyboard if the digits did match and if the digits did not match they were to press the key labeled “mismatch”. Next they were instructed to press the corresponding letter key on the keyboard. And lastly they were told to identify the color of the target letter by pressing the corresponding labeled key on the keyboard.

Consequently, each trial (see Figure 2) began with two asterisks and a fixation point (a "+"). The asterisks cued the participant as to the exact location of the digits. The asterisks and the fixation point remained on the computer screen for 1,500 ms at which point the asterisks were replaced by two digits (the stimuli for the primary task). The digits remained on the screen for 100 ms and then they were joined by a target/distractor pair. Display durations were determined for each individual (see below). Hash marks masked the display after the display disappeared. There were 1,000 ms between trials.

Approximately 3 blocks of thirty-two practice trials were administered to each participant. Display durations were calculated using blocks of 32 practice trials. In an effort to equalize performance and assure that attention was focused as instructed, display durations were calibrated so that each individual performed at approximately 90% accuracy on the digit task.

The WAIS-R vocabulary and digit symbol subscales were administered between the second and third, and the fourth and fifth blocks, respectively. Rest breaks were scheduled between blocks.

Participants responded using labeled keys and the letter keys on a keyboard. In response to cues on the computer screen the participant first reported whether the digits were the same or different, then reported the identity of the target, and last reported the color of the target.

Results

Digit Accuracy

The digit match/mismatch task was used to manipulate the size of the attentional window for the letter identification task. Display durations were adjusted for each individual so that each individual had a digit match accuracy of approximately 90%. To assure that the digit match accuracy was similar for both age groups young and elderly performance on the digit match/mismatch was compared (see Figure 3). A 2x2 mixed design ANOVA was used to compare young and elderly digit match performance in the narrow and the wide attention conditions. Importantly, this analysis yielded no overall effect of age. The mean percentage of correct judgments by the young adults (92.1%, SD = 6.1) did not differ significantly from the percentage achieved by the older adults (87.7%, SD = 9.7). There was an overall effect of attention condition, participants from both age groups were more accurate on the digit match task in the narrow than in the wide condition, $F(1,1) = 47.65$, $p < .001$, but there was no age by window interaction (see Figure 3). In conclusion, young and elderly adults performed at approximately 90% accuracy on the digit match task and their ability to manipulate their span of attention was similar. Mean display duration for the elderly was 1100 ms (SD = 540) and 274 ms (SD=261) for the young adults.

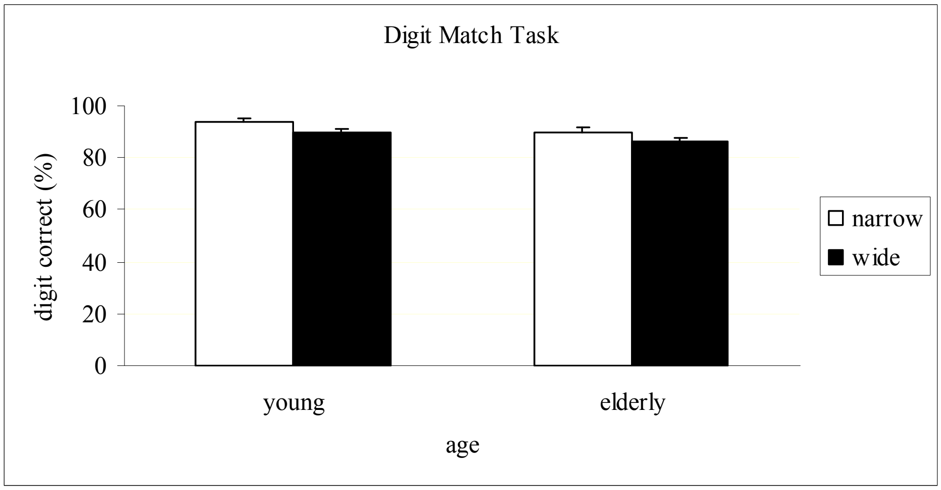


Figure 3. Percent digit correct. Error bars represent the standard error.

Letter Identification

Letter identification was the main focus of this analysis. The attentional demands of the letter identification task were varied by manipulating the location (degree of separation) of the target/distractor pairs and the size of the attentional window created by the primary digit comparison task. Young and elderly adults' response to these demands were compared. Errors, including the incidence of illusory conjunctions, were examined for each attention manipulation and each age group. Two different kinds of statistical analyses were used to examine the data, multivariate and multinomial approaches.

Multivariate Analyses

Types of responses. In the letter identification task responses included selection of the target letter identity and the target color. To assure that the participant had successfully adjusted the size of the attentional window during a particular trial only those letter responses which occurred during trials with correct digit matches were categorized. Performance on both the target letter identity and target color responses was assessed as follows: First, letter correct represents the percentage of occasions when the participant selected the correct letter regardless of the color response. Second, there were three possible color responses in the trials where the target letter was identified correctly: (a) The color is also identified correctly. Tcolor|tletter is the conditional probability that the participant selected the correct target color given that the target letter was correct. (b) The participant selects the color of the distractor given that the letter was correctly selected, i.e., the conditional probability, ncolor|tletter. For example, in a display where the target is a red "X" and the distractor is a green "O" the probability that the participant selects green given that the letter (X) was correctly selected. This is an indicator of an illusory conjunction. (c) The participant selects a color that is not in the display while correctly selecting the target letter (the conditional probability ocolor|tletter). For example, in a display where the target is a red "X" and the distractor is a green "O" the conditional probability that the participant selects purple given that the participant selects "X". See Table 1 for a description of each of the possible responses. Table 2 contains the probability of each type of response at each pair location, in the narrow and wide condition for each age group (see Appendix D for corresponding mean reaction times).

Letter correct. The first analysis focused on letter correct responses, which occurred when the participant selected the correct letter regardless of color. It is useful to

Table 1

Description of Each Type of Response

Type of Response	Description
Correct Response	
Letter correct	The participant selects the correct target letter (regardless of color accuracy).
tcolor|tletter	The probability that the participant chooses the correct target color given that the target letter is correct. That is, the conditional probability, tcolor|tletter, where tcolor is the probability that the participant chooses the correct target color and tletter is the probability that the participant chooses the correct letter.
Errors	
ocolor|tletter	The conditional probability that the participant chooses a color that is not the target color and not the non-target color given that the target letter is correctly reported. That is, the conditional probability ocolor|tletter, where ocolor is the probability that the participants choose a non-display color and tletter is the probability that the participant chooses the correct letter.
ncolor|tletter (illusory conjunctions)	The conditional probability that the participant chooses the color of the non-target given that the target letter is correctly reported.

examine letter correct responses for two reasons: (1) to demonstrate that the display durations were long enough so that the participants were able to correctly identify the target letter more often than would be predicted by chance, and (2) to assure that there were no age-related differences in performance. Overall when the data were collapsed across all conditions and age groups, the participants correctly identified approximately 82% of the letters. Notice that there was a 5% likelihood of selecting the target by chance in the 20 possible target task and a 50% likelihood of selecting the target letter by chance in the two-target version. Thus, performance on the letter identification task was well above chance. The mean accuracy of the young adults' was 80.6% (*SD* = 12.1) and of the older group, 83.0% (*SD* = 9.9). There was no statistically significant difference between the two groups, $t(1, 68) = -0.90$, $p > .05$, (see Figure 4). Hence, both young and elderly adults were able to identify the target letter well above chance, and they were comparable in their ability to correctly identify the letters.

However, analysis of letter identity accuracy also yielded a puzzling result. An ANOVA was used to compare letter identity errors at each combination of age (young, elderly), attentional window (narrow, wide) and location (CD, BE, and AF). A three-way interaction of age, attentional window and location was found marginally

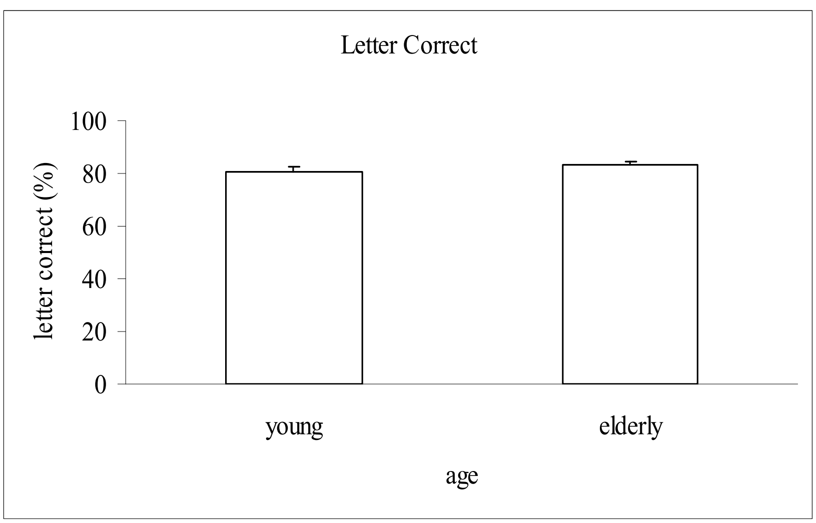


Figure 4. Letter correct for each age group. Error bars represent the standard error.

significant, $F(2,136) = 3.53$, $p < .035$. Further examination of the data showed that elderly letter identification was comparable across window and location. However, young adult letter identification accuracy was lower within the attentional window. T-tests were used to compare young adult performance in the narrow and wide attentional window at each location. Letter identity accuracy was similar at the CD and the AF locations. However, performance was less accurate inside the attentional window at the BE location ($M = 73.9$, $SD = 18.4$) than outside the attentional window at the BE location ($M = 88.5$, $SD = 10.2$), $t(68) = 3.0$, $p < .01$. See discussion section for an in-depth discussion of this result.

Analysis of Attention and Illusory Conjunctions (ncolor|tletter). Illusory conjunctions were evaluated using the conditional probability ncolor|tletter, where ncolor is the non-target color and tletter is a correct target letter. An ANOVA was used to compare the incidence of illusory conjunctions in young and elderly adults. Age (young, elderly) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. This analysis yielded no main effect of age and no significant two or three way interactions with age. It did, however, yield a significant main effect of location, $F(2, 67) = 30.37$, $p < .01$, and a significant location x window interaction, $F(2, 67) = 9.89$, $p < .01$ (see Table2).

Although there were no significant main effects or interactions involving age, a priori hypotheses allow for a comparison of performance in each attentional window

Table 2

Proportion of each Type of Response at each Pair Location in the Narrow and Wide Condition for each Age Group

Young Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
letter correct	.78	.88	.87	.84	.71	.74	.84	.76
tcltl[a]	.73	.85	.88	.82	.70	.72	.85	.76
odcltl[b]	.09	.08	.06	.08	.10	.10	.07	.09
ncltl[c]	.18	.07	.06	.10	.21	.17	.08	.15

Elderly Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
letter correct	.84	.85	.83	.84	.83	.82	.81	.82
tcltl[a]	.60	.71	.72	.68	.63	.63	.74	.67
odcltl[b]	.20	.16	.16	.17	.17	.18	.14	.16
ncltl[c]	.20	.13	.13	.15	.20	.18	.12	.17

[a]Probability of target color corrects given that the target letter is correct

[b]Probability of non-display color errors given that the target letter is correct

[c]Probability of non-target color given that the target letter is correct

(narrow, wide) at each location (CD, BE, and AF) for each age group. Consequently, the following analyses concerning window and location were conducted.

Young adults. It was predicted that young adults would report more illusory conjunctions inside compared to outside the attentional window. Hence, the size of the attentional window would not affect the proportion of illusory conjunctions in the

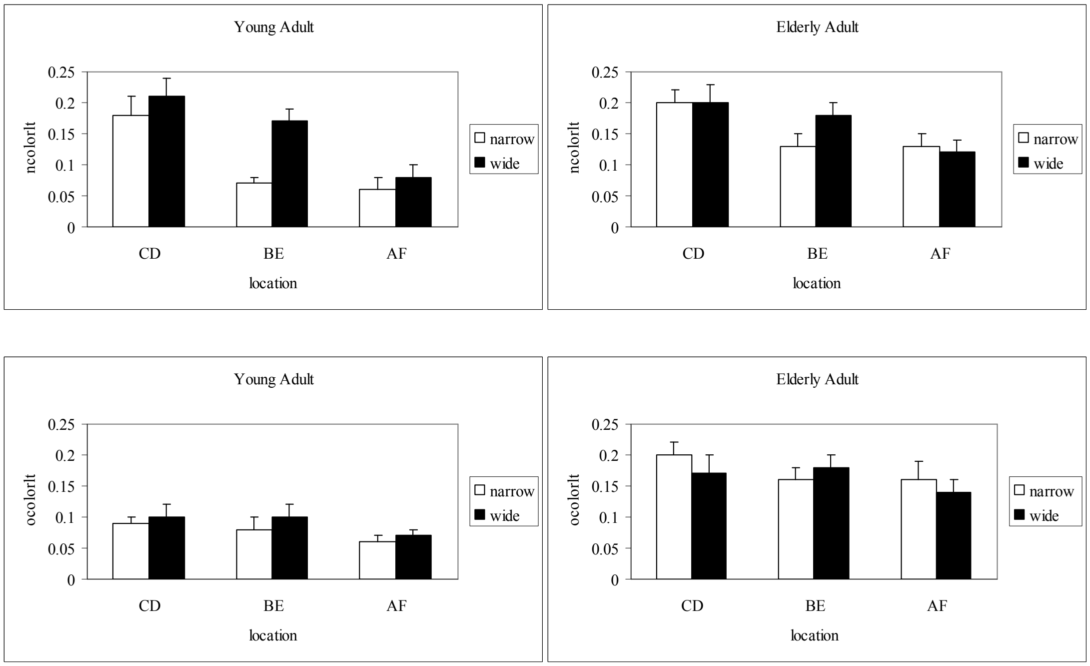


Figure 5. Comparison of ncolor|tl and ocolor|tl for each age group. Error bars represent standard error.

CD and the AF condition. (The AF pair location is outside the attentional window in both the narrow and the wide conditions. While the CD pair location is within the attentional window in both the narrow and the wide conditions). In contrast the proportion of illusory conjunctions in the BE pair location was expected to differ across attentional conditions because BE is outside the attentional window in the narrow condition and inside the attentional window in the wide condition. Fisher's protected T-tests were used to compare the proportion of illusory conjunctions between the narrow and wide attentional conditions at each of the three pair locations, BE, CD and AF (see Figure 5). For the young adults the results were as expected. T-tests comparing illusory conjunctions in the narrow and wide conditions at the CD (where the pair location was inside the span of attention in both the narrow and the wide condition) and the AF positions (where the pair location was outside the span of attention in both the narrow and the wide condition) yielded no significant difference. However, at the BE positions illusory conjunction errors in the narrow (M = .07, SD = .09) were less frequent than in the wide conditions (M = .17, SD = .13), $t(34) = -6.18$, $p <. 01$.

<u>Elderly.</u> T- tests used to compare the proportion of illusory conjunctions at the CD pair location in the narrow and wide condition, and at the AF pair location in the narrow and wide conditions yielded no significant difference between the two attentional conditions. However, a t-test used to compare illusory conjunctions at the BE position showed proportionally fewer errors in the narrow (M= .13, SD = .12) than the wide (M = .18, SD = .13) conditions, $t(34) = -3.79$, $p < .01$. These effects echo young adult performance.

<u>Adjusted data.</u> A potential problem with interpreting these results is that selection of the non-target color – even if it is paired with the correct letter – is not always the result of a binding error. The non-target color may also be selected if the participant is guessing the color of the target. Since, there are only four colors to guess from, the chance of guessing correctly is high. One method to control for the high guess rate is to use ocolor|tletter errors as a baseline for guessing (see Table 2). If the participant were to guess the color of the target, then by chance the participant would

guess twice as many ocolor|tletters as ncolor|tletter errors. This is because there are three (non–target) colors to choose from, the non-target color and the two other colors not in the display. Therefore, the data were corrected for the baserate of ocolor|tletter errors. To this end, the value of ½ (ocolor|letter) was subtracted from each value of ncolor|tletter at each combination of window and condition (see Table 3).

Analysis of the adjusted value of ncolor|tletter was similar to the analysis conducted on the raw scores. An ANOVA was conducted with age (young, old) as the between groups factor, and location (CD, BE, and AF) and window (narrow, wide) as within group factors. This analysis yielded no effect of age or any of the two or three-way interactions involving age.

Young adult adjusted data. Again, a priori hypotheses predicting age differences allow for the following comparisons. Performance in the narrow and wide conditions was compared at each pair location (see Figure 6). There was no difference in performance in the CD location in the narrow ($M = .13$, $SD = .17$) and wide condition ($M = .16$, $SD = .16$). Performance in the AF location in the narrow ($M = .03$, $SD = .07$) and wide conditions ($M = .05$, $SD = .11$) was also similar. And, as previously reported for the raw data, there was a higher incidence of illusory conjunctions in the wide condition ($M = .12$, $SD = .13$) of the BE location than in the narrow condition ($M = .03$, $SD = .08$), $t(34) = -4.66$, $p < .01$.

Elderly adult adjusted data. However when an analysis of ncolor|tcolor corrected for guessing was conducted on the elderly adult data (see above; see Figure 6), t-tests used to compare performance between each condition (narrow, wide) at each

Table 3

Proportion of Non-Target Color Responses and Adjusted Non-Target Color Response at each Pair Location in the Narrow and Location in the Narrow and Wide Conditions

Young Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
adjusted ncltl[a]	0.13	0.03	0.03	0.06	0.16	0.12	0.05	0.11
ncltl[a]	0.18	0.07	0.06	0.10	0.21	0.17	0.08	0.15

Elderly Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
adjusted ncltl[a]	0.10	0.05	0.05	0.07	0.11	0.09	0.05	0.08
ncltl[a]	0.20	0.13	0.13	0.15	0.20	0.18	0.12	0.17

[a]Probability of non-target color given that the target letter is correct

pair location (CD, BE, AF) yielded no significant difference in attentional allocation at the CD (*M* = .10, *SD* = .13 in the narrow condition, *M* = .11, *SD* = .15 in the wide condition), BE (*M* = .05, *SD* = .11 in the narrow condition, *M* = .09, *SD* = .14 in the wide condition), or the AF (*M* = .05, *SD* = .12 in the narrow condition, *M* = .05, *SD* = .13 in the wide condition), pair location. Thus, there was a difference in performance at BE using the raw scores but there was no difference when comparing incidence of adjusted ncolor|tcolor errors.

In conclusion the young adults experience more illusory conjunctions inside the span of attention than outside the attentional window. For the elderly, the

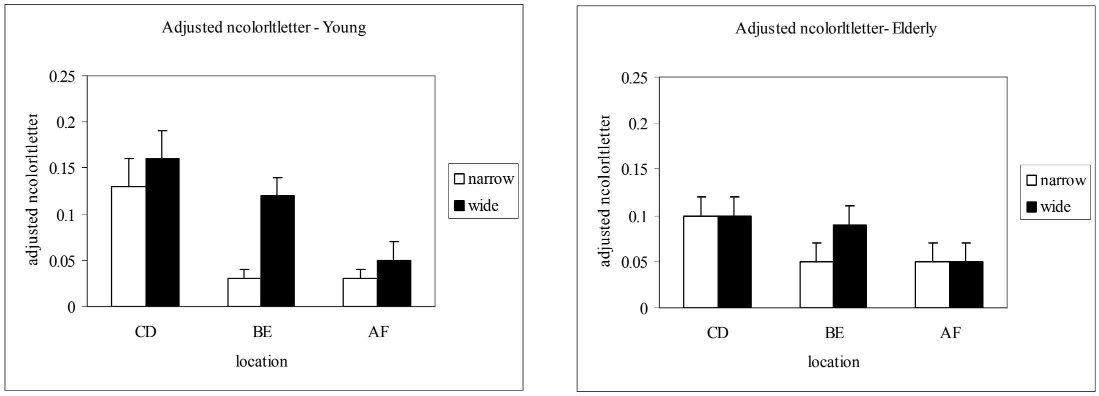


Figure 6. Comparison of adjusted ncolor|tletter for each age group. Error bars represent standard error.

multivariate results are mixed. T-tests that compare performance (using raw scores) at each pair location suggest that the elderly adults perceive more illusory conjunctions within the attentional window than outside of the attentional window. However, a comparison of scores adjusted for guessing yields no difference.

Analysis of location effects within and outside the attentional window. A frequently reported finding in the literature is that incidence of illusory conjunctions increases the closer that the distractor and target are in proximity to each other (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Cohen & Ivry, 1989; Hazeltine, Prinzmetal, & Elliot, 1997, Ivry & Prinzmetal, 1991). Cursory examination of the data support this notion. As reported above, an ANOVA was used to compare the incidence of illusory conjunctions in young and elderly adults. Age (young, elderly) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. The

ANOVA yielded a main effect of location, $F(2, 67) = 30.37$, $p < .01$, and a significant location x window interaction, $F(2, 67) = 9.89$, $p < .01$. To further examine the location effect the incidence of illusory conjunctions was compared between the distractor/target pairs that are inside the attentional window. In addition, those pairs that are located outside the attention window were compared. In the wide condition CD and BE fall within the attentional window (see Figure 1). Thus, a t-test was used to compare incidence of illusory conjunctions (corrected for baserate guessing; see above) in the CD ($M = .16$, $SD = .16$) and BE position ($M = .12$, $SD = .13$) in the wide condition for the young adults. The t-test yielded no significant difference between the groups. In addition, a t-test, used to compare proportions of corrected illusory conjunctions in the outer positions (in the BE position, $M = .03$, $SD = .08$; in the AF position $M = .03$, $SD = .07$) in the narrow condition, also yielded no significant differences.

Location effects were also examined within each attentional window for older adults. A t-test was used to compare corrected (corrected for baserate guessing; see above) incidence of illusory conjunctions in the CD ($M = .11$, $SD = .15$) and BE position ($M = .09$, $SD = .14$) in the wide condition. The t-test yielded no significant difference. In the narrow condition, both BE and AF fell outside the attentional window and it would be expected that these two rates of producing illusory conjunctions should be similar. The outer position (in the BE position, $M = .05$, $SD = .11$; and in the AF position $M = .05$, $SD = .12$) were not significantly different.

In conclusion, multivariate analysis of the young adult data demonstrates that young adults have a higher incidence of illusory conjunctions within the attentional window than outside it. Multivariate analysis of older adult data yields no difference in incidence of illusory conjunctions inside or outside the span of attention. In addition, the incidence of illusory conjunctions does not increase with distance (no location effects) between the target and the distractor for either age group.

Multinomial Analysis

A problem with the previous statistical analysis is its treatment of guessing. In the above conventional analysis (adjusted) illusory conjunction effects were examined using a ratio of illusory conjunctions to simple ocolor|tletters assuming that the participants use a naïve guessing strategy in which all errors are equally likely to occur. However, participants often use more sophisticated guessing strategies. For example, the participant may use information from the non-target color or shape while guessing target identity. Imagine that a participant perceives the non-target color but not the target color. Then the participant might eliminate the non-target color from the potential pool of possible target color identities, and guess one of the three remaining colors. A multinomial statistical model can take this type of sophisticated guessing strategy into account. In addition, a multinomial model may allow for a more direct measure of feature binding than simple illusory conjunctions models do.

Response codes. A multinomial analysis requires recoding the responses. The responses were recoded using two symbols. The first symbol represents accuracy of letter identification, “C” for correct identification and “I ” stands for an incorrect response. The second symbol represents the color response. In this experiment, there were four possible target colors. A "T" stands for correct target color an "N" represents the non-target letter color and O and ∅ represent the two other colors absent from the display. Thus, a correct letter and color response is coded CT. And an incorrect letter response and non-target color response is coded IN.

The first step in a multinomial analysis is to identify each psychological parameter required to complete the task. In this task the following parameters were identified: *tl*, the probability of identifying the target letter correctly; *tc*, the probability of correctly identifying the target color; *nc*, the probability of correctly identifying the non-target color, and; α the probability of correctly binding the target letter to the target color. Notice that the binding parameter,α, measures the probability that the target letter and the target color are correctly bound. Thus, α is a more direct measurement of when two features are correctly bound than illusory conjunctions because it is possible to perceive an illusory conjunction by chance. Imagine a situation where a participant perceives the target letter, incorrectly guesses that the target color is the non-target color, and then correctly binds the two features together. In this situation the participant would report an illusory conjunction, but the participant did not make a binding error. Thus, α is a more direct measure of binding errors than illusory conjunctions. When α is equal to 1 then there is perfect binding and when it equals 0.5 then binding is random.

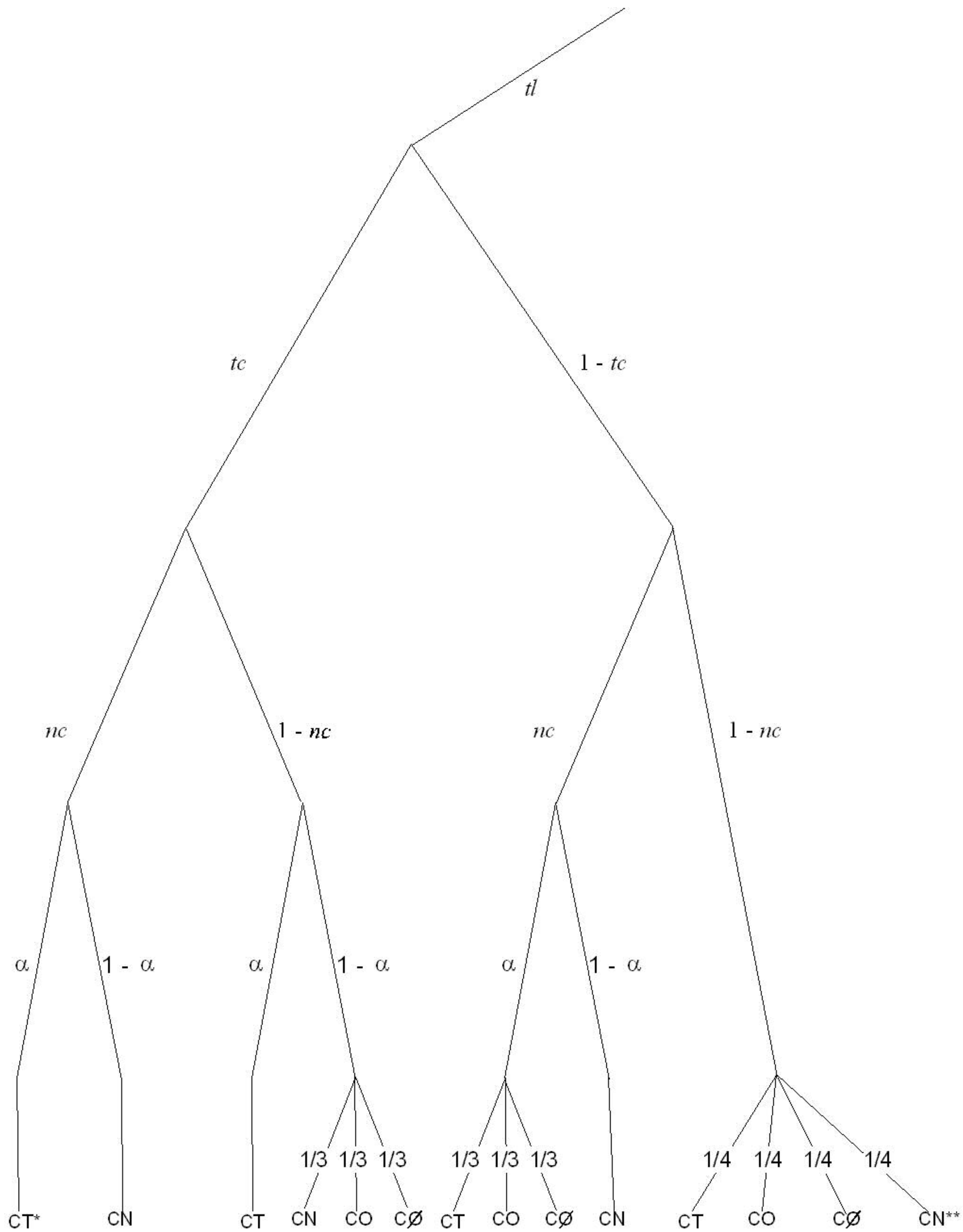
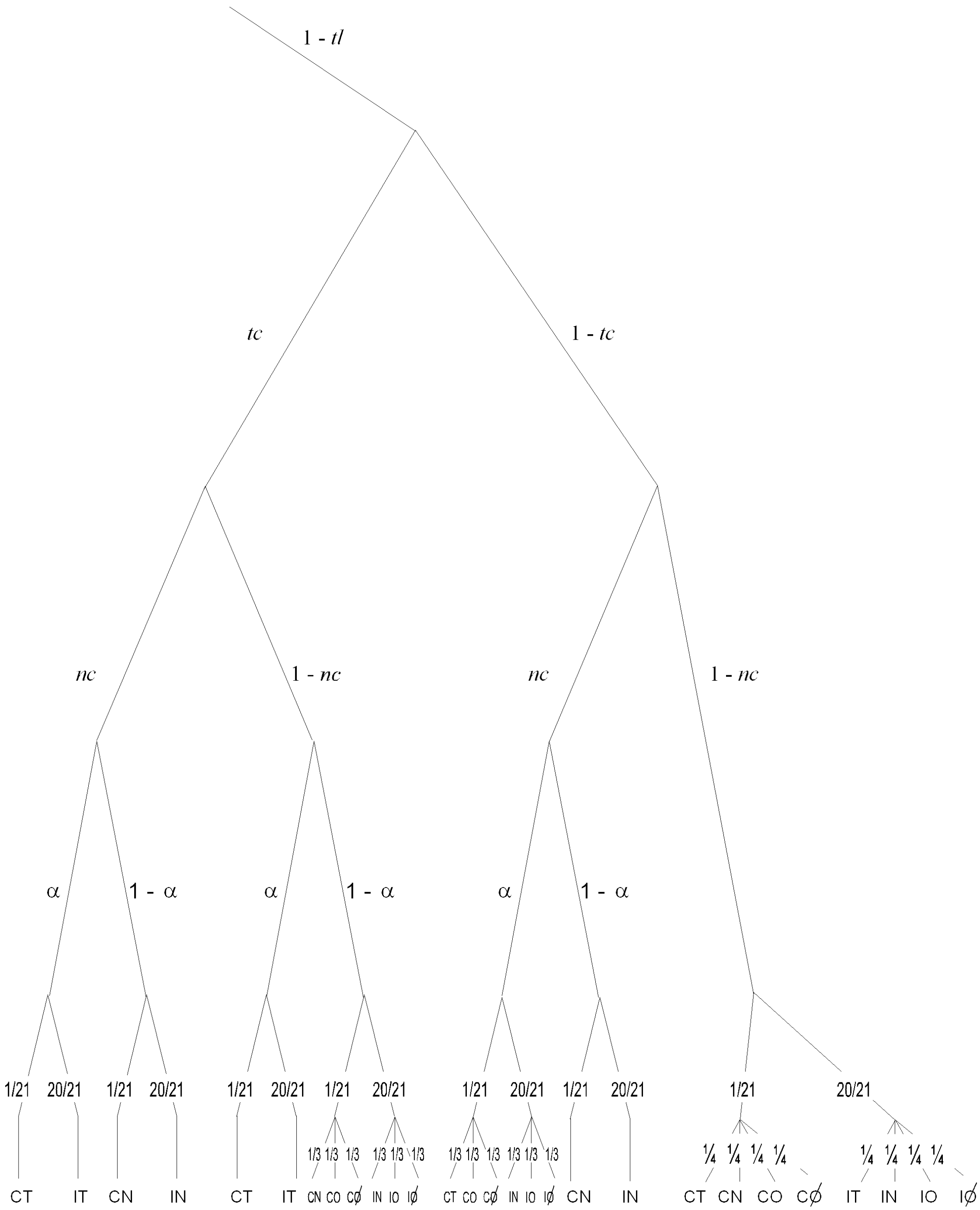


Figure 7. Tree diagram for multinomial analysis. Notice that the *tl* branch and the 1-*tl* branch are on different pages.


1 - tl
tc
1 - tc
nc
1 - nc
nc
1 - nc
α
1 - α
α
1 - α
α
1 - α
1/21 20/21 1/21 20/21 1/21 20/21 1/21 20/21 1/21 20/21 1/21 20/21 1/21 20/21
1/3 1/3 1/3 1/3 1/3 1/3 1/3 1/3 1/3 1/3 1/3 1/3
¼ ¼ ¼ ¼ ¼ ¼ ¼ ¼
CT IT CN IN CT IT CN CO CØ IN IO IØ CT CO CØ IN IO IØ CN IN CT CN CO CØ IT IN IO IØ

The second step in a multinomial analysis is to set up a tree diagram that illustrates the pathways to each type of response (see Figure 7). This tree diagram will be the basis for computing probabilities to be used in the statistical analysis. The tree diagram contains four sequential binary decision points for each of four psychological processes, *tl*(or 1-*tl*), *tc* (or 1-*tc*), *nc* (or 1-*nc*) and α (or 1-α). For example, see CT* on Figure 7. One of the pathways on which CT appears is the one when the target letter is correctly chosen. The pathway that leads to this CT (target letter correct, target color correct) is represented as follows: $tl*tc*nc*\alpha$. That is, the probabilities of the target letter multiplied by target color, multiplied by non-target color and multiplied by the binding parameter. Notice that there are 8 pathways that lead to CT.

The third step in the analysis is calculating the probability of a specific response. The probability of a specific response is the sum of all the pathways that end in that particular response. For example (see Appendix 3 for the probability of each response), the probability of CT is calculated as follows (see Figure 7):

$$
\begin{aligned}
P(CT) = {} & (tl*tc*nc*\alpha) \\
& +(tl*tc*(1-nc)*\alpha) \\
& +(tl*(1-tc)*nc*\alpha*0.33) \\
& +(tl*(1-tc)*(1-nc)*0.25) \\
& +((1-tl)*tc*nc*\alpha*0.05) \\
& +((1-tl)*tc*(1-nc)*(\alpha)*0.05)
\end{aligned}
$$

$+((1-tl)*(1-tc)*nc*\alpha*0.05*0.33)$

$+((1-tl)*(1-tc)*(1-nc)*0.05*0.25)$

Notice that illusory conjunctions (CN) can occur by a number of pathways in addition to those where there are binding errors. For example, illusory conjunctions can occur as follows: see the pathway that leads to CN** ($tl*(1-tc)*(1-nc)$). In this example, the participant perceives the target letter, does not perceive the target color or the nontarget color. Since there are four possible target color choices, there is a 25% chance that the participant will choose the nontarget letter, leading to a CN response. But, this CN occurred by chance - not as a result of erroneously combining the letter with the nontarget color. Thus, when CN is the measure of illusory conjunctions, it may overestimate binding errors.

Step four is to find an estimate of each psychological parameter (*tl, tc, nc*, α) This was accomplished using G^2, a goodness-of-fit measure, that finds the best fit between the predicted probabilities (see Appendix 3) and the observed proportions by adjusting the parameters *tl*, *tc*, *nc*, and α.

G2 is calculated as follows:

$G^2 = \Sigma\ (2*ObsFreq_i) * \ln(ObsProp_i/ObsPred_i)$

Where $ObsFreq_i$ is the observed frequency of each response type, $ObsProp_i$ is the observed proportion of each response type, and $ObsPred_i$ is the predicted probability that the response will occur.

Table 4

Multinomial value at each Pair Location in the Narrow and Wide Condition for each Age Group

Young Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
tl	0.66	0.82	0.81	0.77	0.54	0.62	0.77	0.65
tc	0.85	0.88	0.91	0.88	0.79	0.83	0.88	0.83
nc	0.71	0.72	0.83	0.75	0.73	0.69	0.76	0.73
α	0.77	0.9	0.9	0.86	0.72	0.76	0.87	0.78

Elderly Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
tl	0.72	0.76	0.77	0.75	0.72	0.72	0.73	0.72
tc	0.69	0.77	0.75	0.73	0.7	0.67	0.75	0.71
nc	0.71	0.61	0.65	0.66	0.60	0.53	0.62	0.58
α	0.75	0.84	0.82	0.8	0.75	0.77	0.82	0.78

The multinomial equation was solved using a program called Solver. Solver is available on Microsoft Excel. See Dodson, Prinzmetal and Shimamura (1998) for a detailed description of using Solver to solve multinomial equations. For a more in-depth description of using multinomial equations to examine behavioral issues see Riefer and Batchelder (1988).

Analysis of the letter identification parameter (tl). See Table 4 for the value of each of the multinomial parameters at each pair location, in the narrow and wide condition for each age group. Consistent with the multivariate analysis there was no age difference in ability to correctly identify the letters. The mean value of the letter identification parameter (TL) of the young adults' was .71 (*SD* = .26) and of the older group .74 (*SD* = .20). There was no statistically significant difference between the two groups, $t(1, 67) = -0.67$, $p > .01$, (see Figure 8). Hence, both young and elderly adults were comparable in their ability to correctly identify the letters.

Analysis of attention and the binding parameter (α). The binding parameter is used as a more direct measure of erroneous combination of target features than illusory conjunctions. The same statistical analyses were conducted on the binding parameter (alpha) that were conducted on the incidence of illusory conjunctions. An ANOVA was used to compare the binding parameter (α) for young and elderly adults. Age (young, elderly) was a between factor. Location (CD, BE, and AF) and window (narrow, wide) were within factors. This analysis yielded no significant main effect of age and no two-way or three-way interactions with age. (It did, however, yield a significant main effect of window, $F(1,67) = 23.21$, $p < .01$, location, $F(2,66) = 23.87$, $p < .01$, and window x location interaction, $F(1,66) = 7.04$, $p < .01$. See below for discussion of location effects).

Although there were no significant effects involving age, since an age difference in the pattern of incidence of illusory conjunctions (and hence in binding errors) in the narrow and wide attentional conditions was hypothesized a priori, the following statistical analyses concerning age were conducted.

<u>Young adults</u>. Fishers protected t-tests were used to compare α at each pair location (CD, BE, AF) in the narrow and wide conditions. No significant difference between attentional conditions was found at the CD (narrow *M* = .77, *SD* = .18; wide

M = .72, SD = .17) and AF (narrow *M* = .90, *SD* = .11; wide *M* = .87, *SD* = .14) location. As expected, there was a significant difference at the BE position with better binding in the narrow (*M* = .90, S*D* = .12) than the wide condition (*M* = .76, *SD* = .15), $t(68) = 4.43$, $p<.01$. Recall that in the narrow condition the BE position is outside the span of attention. Thus, as expected, the young adults were better at binding outside the span of attention.

Elderly adults. Elderly adults' binding parameter data were also examined. T-tests, used to compare α at each pair location (CD, BE, AF) in the narrow and wide conditions, yielded no difference at the CD (narrow *M* = .75, *SD* = .19; wide *M* = .75, *SD* = .19), BE (narrow *M* = .84, *SD* = .17; wide *M* = .77, *SD* = .17), or AF (narrow *M* = .82, *SD* = .18; wide *M* = .82, *SD* = .17) location. These results are consistent with the multivariate results. Thus, allocation of attention did not affect the perception of illusory conjunctions at each of the three target- distractor locations.

Analysis of location effects within and outside the attentional window. A frequently reported finding in the literature is that incidence of illusory conjunctions increases the closer that the distractor and target are in proximity to each other (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Cohen & Ivry, 1989; Hazeltine, Prinzmetal, & Elliot, 1997, Ivry & Prinzmetal, 1991). The ANOVA reported above used to compare the binding parameter (alpha) in young and elderly adults was used to evaluate this claim. Age (young, elderly) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. The ANOVA yielded a main effect of location, $F(2, 66) = 23.87$, $p< .01$, and a significant location x window interaction,

$F(2, 66) = 4.04$, $p < .01$. To further examine the location effect, the binding parameter was compared between the distractor/target pairs that are inside the attentional window. In addition, those pairs that are located outside the attention window were compared. In the wide condition CD and BE fall within the attentional window (see Figure 1).

Young adults. A t-test was used to compare the binding parameter in the CD ($M = .72$, $SD = .17$) and BE position ($M = .76$, $SD = .14$) in the wide condition for the young adults. The t-test yielded no significant difference between the groups. In addition, a t-test, used to compare the binding parameter in the outer positions (in the BE position, $M = .90$, $SD = .10$; in the AF position $M = .90$, $SD = .10$) in the narrow condition, also yielded no significant difference. Thus, as expected there was no location effect for the young adults.

Elderly adults. Location effects were also examined within each attentional window for older adults. A t-test was used to compare the binding parameter in the CD ($M = .75$, $SD = .20$) and BE position ($M = .77$, $SD = .17$) in the wide condition. The t-test yielded no significant difference between the groups. In the narrow condition, both BE and AF fell outside the attentional window and it would be expected that the binding parameter should be similar. The outer position (in the BE position, $M = .84$, $SD = .17$; and in the AF position $M = .82$, $SD = .17$) were not significantly different. There was no location effect for the elderly.

In summary, multinomial analyses of the data are consistent with the multivariate analyses. Young adults observe more illusory conjunctions and have more binding errors inside the attentional window. The elderly demonstrate no difference in the number of illusory conjunctions or binding errors as a function of attentional window. Neither the multinomial or multivariate analysis yielded support for a location effect for either age group.

Low vs. High Functioning Subjects

Recent research suggests that an alternative explanation for age differences in an executive function task (such as a task that requires attention) may be due to an age related difference in ability to perform the basic skills required to do the task. The present research requires basic skills such as psychomotor speed, facility with the alphabet and numbers, hand-eye coordination, etc. The WAIS vocabulary and WAIS digit-symbol subtests measure some of these basic skills. To test the possibility that the age differences found in the present experiment could be better explained by differences in basic skills rather than differences in allocation of attention, the WAIS subscales were used to group the data and differences between high-functioning and low-functioning subjects were examined. For each age group, those who scored in the top third of the WAIS vocabulary subscale, the high – functioning verbal group, were compared with those who scored in the bottom third of the WAIS vocabulary subscale, the low-functioning verbal group. For the young adults an ANOVA was used to compare the binding parameter (α) of the high (WAIS vocabulary subscale ranged from 54-66, M = 58.8) and low-functioning verbal groups (WAIS vocabulary subscale ranged from 26-40, M = 35.2). Group (high-functioning, low-functioning) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. The ANOVA yielded no significant effect of WAIS group. Fishers protected t-tests were used to compare α at each pair location (CD, BE, AF) in the narrow and wide conditions in the low-functioning condition. In the low functioning group, no significant differences between attentional conditions were found at the CD (narrow *M* = .75, *SD* = .18; wide *M* = .72, *SD* = .18), AF (narrow *M* = .84, *SD* = .14; wide *M* = .82, *SD* = .14) and BE positions (narrow *M* = .87, *SD* = .14; wide *M* = .78, *SD*= .14.) In the high-functioning verbal group there was no significant difference between attentional conditions in the CD (narrow *M* = .73, *SD* = .19; wide *M* = .64, *SD* = .13) and AF positions (narrow *M* = .91, *SD* = .11; wide *M* = .89, *SD* = .13.) There was a significant difference at the BE position with better binding in the narrow (*M* = .93, *SD* = .09) than the wide conditions (*M* = .71, *SD* = .13), $t(50) = 2.69$, $p<.01$. For the young adults the pattern of responses differed in the low and high-functioning verbal groups. The high-functioning group pattern of response was similar to the results found in the Experiment 1 for the entire sample of young adults. However, the low-functioning group's pattern of binding errors was similar to elderly adult performance. It is possible that the pattern of results found in Experiment 1 was only valid for the high-functioning young adults and that the low-functioning young adult's results were similar to elderly adult performance.

The elderly low and high functioning verbal groups were also compared. An ANOVA was used to compare the binding parameter (α) of the high- functioning verbal (range of WAIS – vocabulary subscale is 64-68, *M* = 65.8) and low-functioning verbal elderly groups (range of WAIS- vocabulary subscale is 20-58, *M* = 49.3).

Group (high-functioning, low-functioning) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. The ANOVA yielded no significant effect of WAIS group. T-tests were used to compare attentional condition at each pair/distractor location. For the low-functioning group there was no difference between the attentional conditions at the CD (narrow $M = .79$, $SD = .19$; wide $M = .73$, $SD = .16$), AF (narrow $M = .82$, $SD = .16$; wide $M = .84$, $SD = .11$) and BE conditions (narrow $M = .85$, $SD = .15$; wide $M = .72$, $SD = .21$.) For the high-functioning group there was also no significant difference between attentional conditions at the CD (narrow $M = .72$, $SD = .20$; wide $M = .74$, $SD = .23$), AF (narrow $M = .84$, $SD = .20$; wide $M = .80$, $SD = .17$) and BE positions (narrow $M = .83$, $SD = .16$; wide $M = .73$, $SD = .15$.) The elderly adults' pattern of binding errors was not statistically different in either the low or high-functioning verbal group. And this pattern was similar to the overall pattern of result found in Experiment 1.

The WAIS digit-symbol subscale was also used as a grouping factor. An ANOVA was used to compare α of a high-functioning digit-symbol group (range = 74-89, $M = 79.2$) with a low-functioning group (range = 32-65, $M = 52.3$). Group (high-functioning, low-functioning) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors. The ANOVA yielded no significant effect of group. For the young adults in the low-functioning digit symbol group there was no significant difference between the number of binding errors in the narrow and wide condition at any location. That is, there was no significant difference between performance at the CD position in the narrow ($M = .74$, $SD = .20$) and the wide condition (*M* = .66, *SD* = .06); the BE position in the narrow (*M* = .85, *SD* = .10) and wide condition (*M* = .85, *SD* = .11) or the AF position in the narrow (*M* = .84, *SD* = .11) and wide position (*M* = .75, *SD* = .16.) T-tests used to compare high-functioning young adults yielded different results. There was no difference in performance at the CD (narrow *M* = .77, *SD* = .19; wide *M* = .73, *SD* = .20) and AF (narrow *M* = .90, *SD* = .11; wide *M* = .85, *SD* = .16) positions. However, there were more binding errors in the narrow condition of the BE position (*M* = .89, *SD* = .13) than at the wide condition of the BE position (*M* = .74, *SD* = .17), $t(44) = 3.75$, $p<.01$.

The elderly low-functioning (range = 32-42, *M* = 39.0) and high-functioning digit symbol group (range = 54-74, *M* = 61.8) were also compared. An ANOVA was used to compare α of a high-functioning digit-symbol group with a low functioning group. Group (high-functioning, low-functioning) was a between factor and location (CD, BE, and AF) and window (narrow, wide) were within factors.   The ANOVA yielded no significant effect of group. There was no difference in the attentional conditions at each position of CD (narrow *M* = .70, *SD* = .14; wide *M* = .79, *SD* = .23), AF (narrow *M* = .87, *SD* = .19; wide *M* = .82, *SD* = .17) and BE positions (narrow *M* = .85, *SD* = .16; wide *M* = .81, *SD*= .18) in the low-functioning digit symbol group. The high-functioning group also yielded no statically significant differences between the target/distractor position in each attentional condition; CD (narrow *M* = .69, *SD* = .17; wide *M* = .67, *SD* = .17), AF (narrow *M* = .84, *SD* = .16; wide *M* = .80, *SD* = .18) and BE conditions (narrow *M* = .82, *SD* = .17; wide *M* = .72, *SD*= .17.)

In summary, comparison of low and high-functioning verbal and digit-symbol groups suggest a difference in young adult pattern of results but not elderly adults' pattern of results. Young adult performance differed in that the high-functioning young adults' pattern of results was similar to the results of Experiment 1 and the low-functioning pattern of results was similar to elderly adult performance in Experiment 1.

Split – Half Reliability

The reliability of the measures in this experiment was measured using split-half reliability. That is, the Pearson product-moment correlation between the correct trials that occur on the even numbered responses and the number of correct trials that occur on the odd numbered responses was computed and used to measure the reliability of the test. There was a fairly high correlation between the even and odd correct responses, $r= +.91$.

Discussion

The pattern of results differed for young and elderly adults. Young adults' pattern of results is consistent with Cohen and Ivry (1989). That is, the young adults were more susceptible to illusory conjunctions inside the span of attention. The elderly, however, are just as likely to perceive illusory conjunctions inside as outside the span of attention. The results suggest that selective attention is an age related differentiating factor in the susceptibility to illusory conjunctions. Younger adults were more influenced by manipulation of the attentional window and produced more illusory conjunctions within the window than outside it.

In this experiment it is difficult to disentangle the effects of location and attention. The closer the distance between the target/distractor pair the closer the pair is to fixation, thus the two variables are confounded. For example, in the CD target/distractor pair location the target and distractor are closer to each other than in any other pair location, and they are also the closest target/distractor pair to fixation. It cannot be determined how much of the increase in the incidence of illusory conjunctions near fixation is due to a location effect and how much to an attentional effect. Other researchers have reported that illusory conjunctions are more likely in young adults between target and distractors that are located close to each other (Ashby, Prinzmetal, Ivry, & Maddox, 1996; Cohen & Ivry, 1989; Hazeltine, Prinzmetal, & Elliot, 1997, Ivry & Prinzmetal, 1991). Since the results showed an overall effect of location and a location x window interaction (using both multivariate and multinomial analyses) there is some evidence that the number of illusory conjunctions might be partly due to the location of the pair. However, comparison of the number of illusory conjunctions within each attentional window suggests that there is no effect of location within each attentional window. It may be that there is a location effect except within the attentional window. Perhaps attention lessens the location effect.

A puzzling result is that TL (target letter correct) tended to decrease the closer the target-distractor pair was to fixation. That is, when the target/distractor pair was in the CD position there were more target letter identity errors than when the pair was located in the EF position. This phenomenon was also observed by Cohen and Ivry (1989). In 1996, Ashby, Prinzmetal, Ivry, and Maddox attributed this phenomenon to lateral masking. Prinzmetal, Ivry, Beck and Shimizu (2000) designed an experiment that disentangles this potential confound. Prinzmetal, et al. used a display where the target and distractors were equidistant from fixation. Hence, the distance between the distractor and the target could be varied while keeping the distance of each display item from fixation the same. This assured that the identification of the target and distractor was independent of the binding parameter. In the Prinzmetal et al. experiment TL distance from fixation did not vary with target/distractor pair distance. Yet they still found that binding errors tend to occur when the target-distractor pair was closer together. Thus, it is unlikely that in the present experiment TL errors alone can be used to explain the increase in illusory conjunction associated with an increase in target-distractor proximity.

Recall that display duration was calculated separately for each subject. Consequently, the elderly adults were exposed to the display for a longer duration than the young adults. It is possible that the longer display duration changed the elderly adults' performance in ways other than by increasing the number of correct digit matches. Recall that the criterion used to determine the display duration was 90% accuracy on the digit task. It is possible that the additional time also allowed the elderly to correctly bind the color and identity of the target – perhaps the time it takes to bind, unlike the digit match task, is preserved with age and consequently is accomplished more rapidly than the digit match. Had the older adults responded more quickly they may have showed a different pattern of results.

CHAPTER 3: EXPERIMENT 2

Description of Experiment 2

Experiment 2 was designed to determine if the age differences in errors found in Experiment 1 were due to the complexity of the secondary task in Experiment 1. It is possible that age differences in illusory conjunction errors in Experiment 1 are due to age differences in the dual properties of the letter identification task. Experiment 2 is designed to test this possibility. In Experiment 1 the subjects are required to respond by specifying the letter and the color of the target (a dual task and a more complex task). In Experiment 2 the participants are only required to identify the color of the target (a single task). The results of Experiment 1 (the dual task) are compared with the results of Experiment 2 (a single task). Hence, a comparison of color identity performance in a dual task and the color identity in a single task can be used to compare single vs. dual task performance.

Hypothesis

4. Color identification accuracy in the single property condition and the dual property condition will be compared for both age groups. Young adult accuracy in color identification in the dual property condition will be compared with young adult accuracy in color identification in the color alone condition. If young adult color identification performance is comparable in the dual and single property conditions then performance will not be due to single vs. dual task differences. However, if

younger adult performance is compromised in the dual property condition then performance is, at least in part, due to a decrement associated with completing two tasks. Elderly adult performance on color identification in the dual and the single property task will also be compared. If the elderly perform as well on the dual property task as they do on the color alone task, then older adult's response to changes in the attentional window is not compromised when color identification and letter identification are performed concurrently, and older adult performance were not due to deficits in dual property search. If, however, performance is compromised in the dual task condition, then performance is partly due to a decrement associated with dual property task performance.

Methods

Participants

Fifty-nine adults participated in this experiment. Thirty (fifteen in each age group) of the participants were the same as those in Experiment 1 (and they constituted the dual task group). The remaining 29 were new participants. Overall, there were 30 young adults ranging in age from 17 to 33 with a mean age of 20.4 (SD = 4.1). The 29 elderly adults ranged in age from 59 to 89 with a mean age of 74.1 (SD = 6.8). The younger adults were recruited from the University of Maryland and received class credit in return for their participation. The elderly adults were recruited from community programs around University of Maryland, Drake University, and Delaware, Ohio. The elderly adults received five dollars in return for their participation. The elderly adults attended more years of school (M = 16.6, SD = 1.7) than the younger adults (*M* = 13.8, *SD* = 1.7), *t*(57) = -5.35, *p* < .01. The younger adults scored higher (*M* = 65.9, *SD* = 11.8) on the WAIS-R (Wechsler, 1981) digit symbol subscale than the elderly adults (*M* = 44.6, *SD* = 12.4), *t*(56) = 6.71, p < .01. The elderly adults performed better (*M* = 54.4, *SD* = 11.3) on the WAIS-R verbal subscale than the younger adults (*M* = 46.7, *SD* = 11.7), *t*(55) = 2.52, *p*< .01. Visual acuity was determined for each participant using the Rosenbaum Pocket Vision Screener and all participants had vision of 20/30 or better. The participants were screened for color vision using the Pseudo-Isochromatic Plate test and only those with good color vision participated.

Design

In Experiment 2, single-property color identification data were collected to compare with dual-property letter-color identification data collected in Experiment 1. Thus, the design of the stimuli and the procedures were similar except that in the single property task condition the participants only reported the color of the letter. In Experiment 2 there were two conditions, the dual-property condition, where the participants were required to identify the color and the identity of the letter and the single-property condition where the participants reported only the color of the letter. As in Experiment 1 there were two attention window (narrow, wide) and three location pairs (CD, BE, and AF).

Results

The following analyses were used to compare the young and the elderly adults' performance on a single and a dual property version of Experiment 1. Young and elderly adult performance in the single-property condition (where only a color response was required) and the dual-property condition (where both the letter and the color were selected) were compared. Performance on digit-match accuracy, proportion target-color corrects, proportion non-display color errors (ocolor; the color was not in the display) and proportion non-target color errors were also compared (ncolor).

Performance on the Digit Match/Mismatch Trials

The digit match/mismatch task was used to adjust the size of the attentional window. And accuracy of this task was adjusted for each participant so that each individual performed at approximately 90 %. An ANOVA was used to compare young and elderly performance on the single and the dual property conditions. The independent variables were condition (single-property, dual-property), and age (young, elderly). The dependent variable was digit-match accuracy. This analysis yielded no significant main effect of age or condition and no significant interaction. The means for the young adults were 91. 8% (*SD* = 3.7) in the single-property condition and 92.1% (*SD* = 6.2) in the dual-property condition. Elderly performance in the single-property condition averaged 89.5% (*SD* = 12.3) and in the dual-property condition averaged 84.8%, *SD* = 11.9.

Performance on the Letter-Task

There were three possible color response categories in the letter task. The participants could have selected the color of the target letter correctly; or incorrectly selected the non-target color (ncolor); or incorrectly selected a non-display color (one

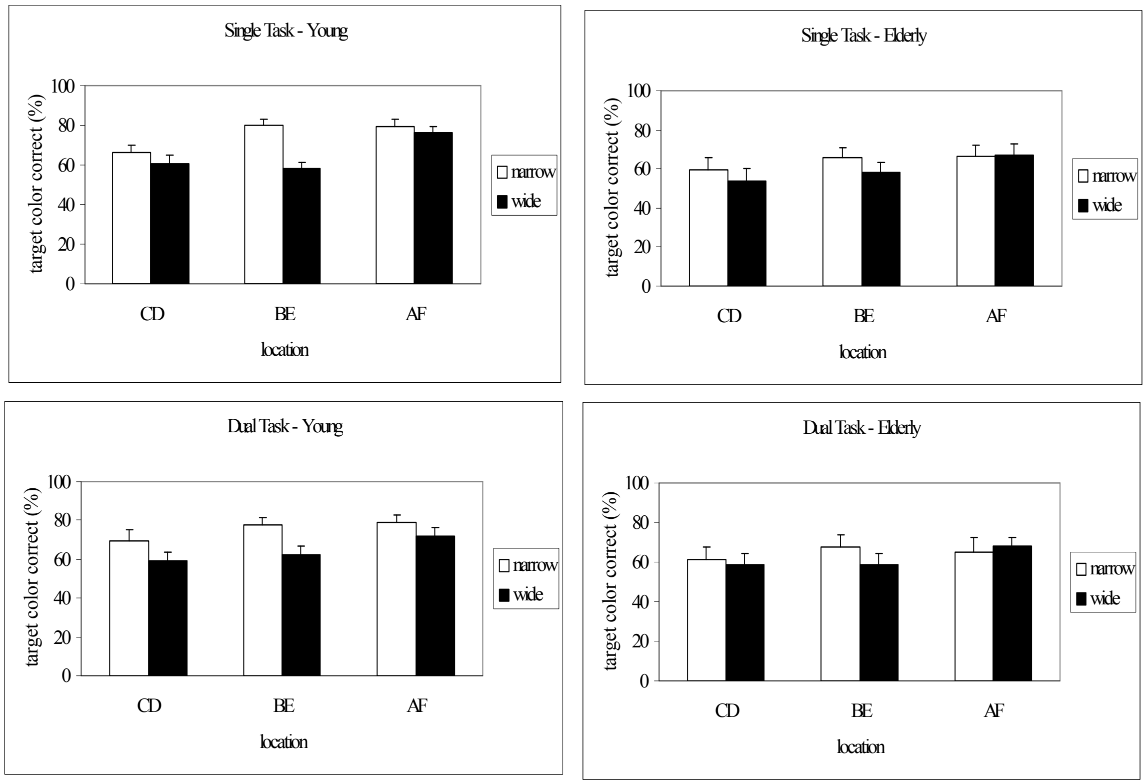


Figure 8. Comparison of the percent target color correct in the single and dual task conditions. Error bars represent standard error.

of the colors that was not in the display; ocolor). To assure that the participants were correctly adjusting the size of their attentional window target color accuracy and target color errors were computed for correct digit-match trials only. Color identification accuracy and color errors in each combination of age, attentional window, condition, and pair location were totaled and divided by the total number of trials (for that combination of age attentional window condition and pair location).

Target Color Correct

An ANOVA was used to compare correct target color responses on single and dual property tasks. The between subject variables were age (young, old) and condition (single vs. dual) and the repeated measures were attentional window size (narrow, wide) and target pair location (CD, BE, AF). This analysis yielded no significant effect of condition and no significant effect of any of the two, three or four-way interactions with condition (Figure 8). Also, there was no significant two, three or four-way interaction with age.

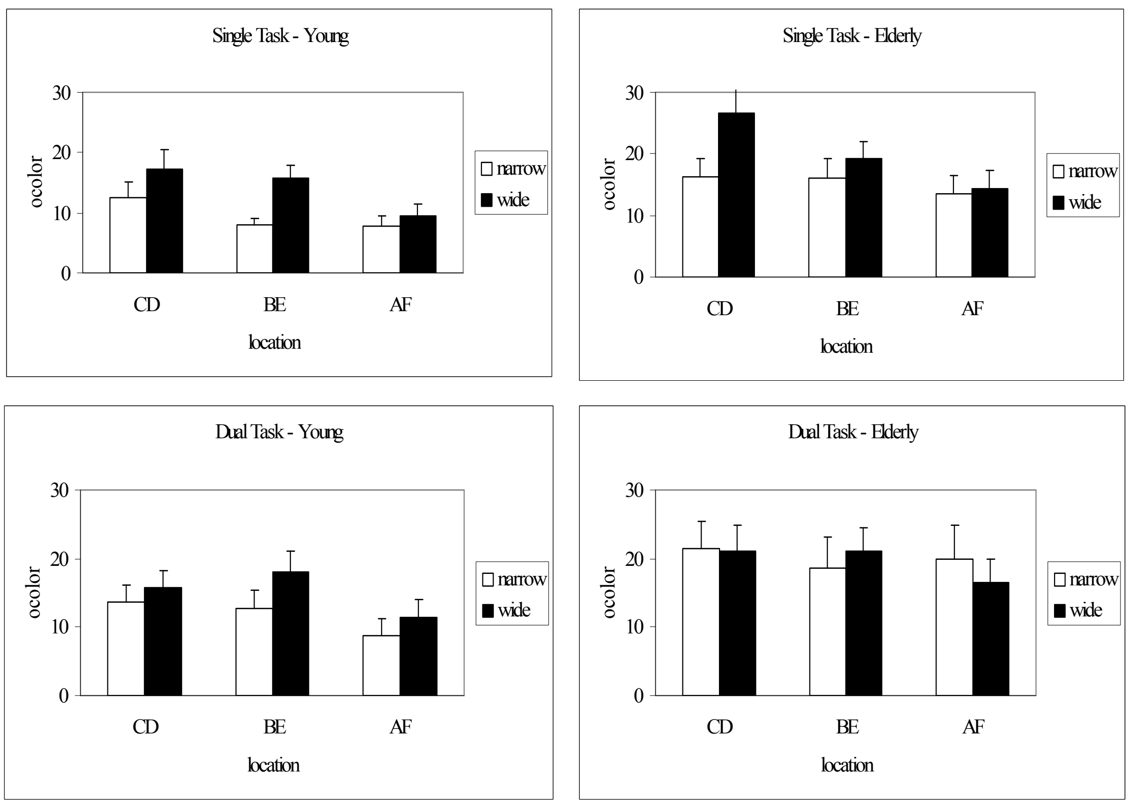


Figure 9. Comparison of ocolor in the single and dual task conditions. Error bars represent standard error.

Non-Display Color Errors (ocolor)

Notice that a non-display color error is not an illusory conjunction because in this case the subject selects a target color that is not in the display. For an illusory conjunction to occur the subject must erroneously select the distractor color; see below.

An ANOVA was used to compare non-display color errors in the dual-property condition with non-display errors in the single property condition (see Figure 9). As in the previous analysis, the independent variables were age (young, elderly), pair location (CD, BE, AF), attentional window size (narrow, wide), and condition (single-property, dual-property). The dependent variable was the proportion of non-display color errors. The analysis yielded no significant main effect of condition. In addition, there were no statistically significant two, three, or four-way interactions involving condition. There was also no significant two, three, or four-way interaction involving age.

Non-Target Color Errors (ncolor; Illusory Conjunctions)

Performance on single and dual property tasks was also compared using non-target color errors (ncolor; see Figure 10). This measurement was used to measure illusory conjunctions in Experiment 2. Recall that in Experiment 1 illusory conjunctions were measured using the conditional probability ncolorltletter. However, in Experiment 2 since the subjects were not required to identify the letter, a conditional probability involving target letter accuracy is not possible. Thus, the non-target color errors were analyzed using an ANOVA. The independent variables were age (young, older), condition (single-property, dual-property), attentional window (narrow, wide), and pair location (CD, BE, AF). The ANOVA yielded no significant difference in condition and no significant two, three or four-way interaction involving condition (including those involving age and condition). Further comparisons of each

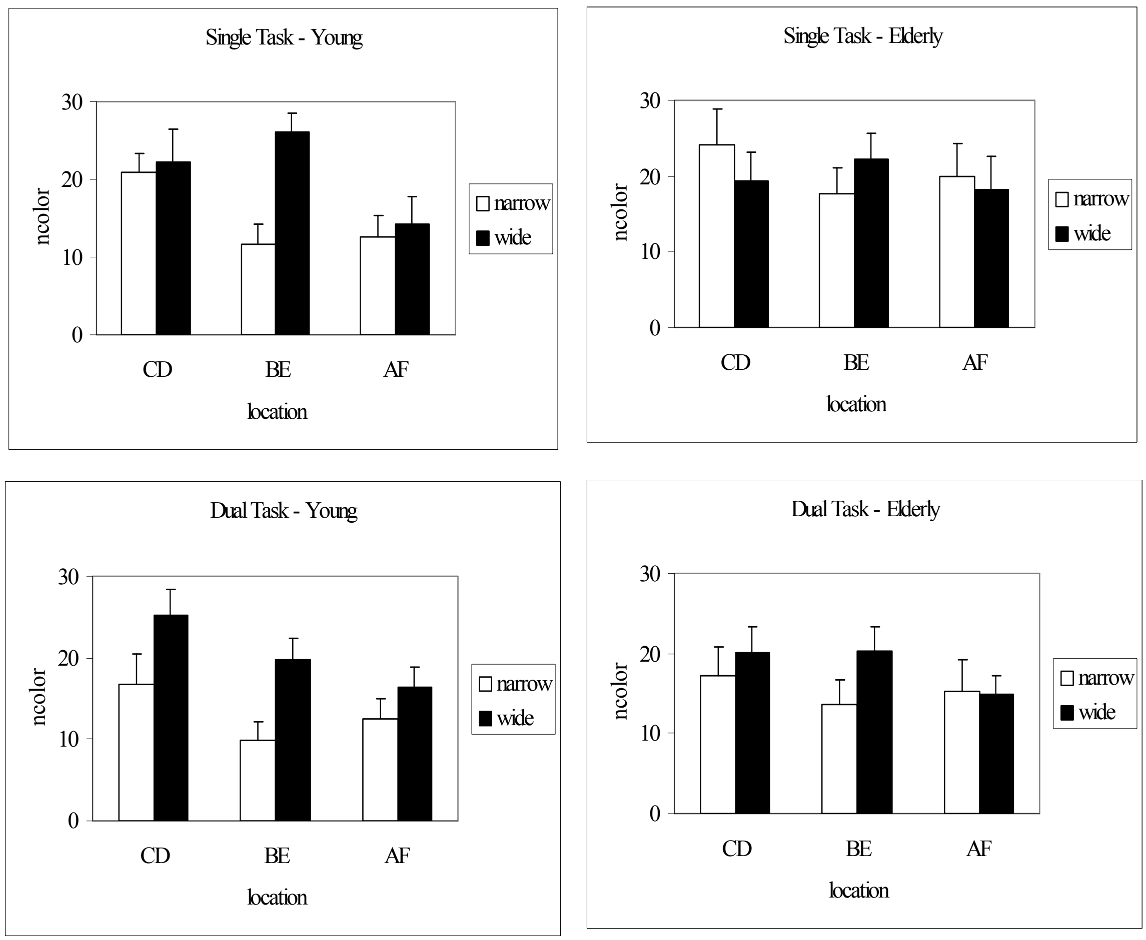


Figure 10. Comparison of ncolor in the single and dual task conditions. Error bars represent standard error.

target/distractor pair in each attention window was warranted given a priori hypotheses that incidence of illusory conjunctions would be higher inside the attentional window.

Young adults. T-tests were used to further analyze the pattern of illusory conjunctions in the dual property condition. The proportion of illusory conjunctions in the narrow and wide attentional conditions at each of the three pair locations, BE, CD and AF (see Figure 10) was compared. T-tests comparing illusory conjunctions in the narrow and wide conditions at the CD (where the pair location was inside the span of attention in both the narrow and the wide condition) and the AF positions (where the pair location was outside the span of attention in both the narrow and the wide condition) yielded no significant difference. In the dual property condition, at the BE position illusory conjunction errors in the narrow (M = 9.8, SD = 9.2) were less frequent than in the wide conditions (M = 19.8, SD = 10.2), $t(28) = 2.86$, $p < .01$. The single property condition had a similar pattern of results. There was no statistically significant difference between incidence of illusory conjunctions in the narrow and wide attentional windows at the CD and the AF positions. And as in the dual property condition there was a lower incidence of illusory conjunctions in the narrow attention condition (M = 11.7, SD= 10.0) than in the wide attention condition (M = 26.1, SD = 9.6), $t(28) = 4.02$, p < .01. The above analyses suggest that the pattern of illusory conjunctions errors was similar in the single and dual property conditions for the young adults.

Elderly adults. The incidence of illusory conjunctions in the single and the dual property conditions was also examined for the elderly adults. In the dual condition t-tests were used to compare illusory conjunctions in the narrow and wide attentional windows at each target/distractor pair location. In the dual property condition there was no difference in performance in the narrow and wide attentional conditions at the CD, BE or AF target/distractor pair location. Analyses of the single property condition yielded similar results; incidence of illusory conjunctions in the narrow and wide attentional windows was similar at each of the target/distractor pair locations. The elderly adult data also suggest that the pattern of errors was similar for the single and dual property conditions.

Discussion

Performance on Experiment 2 (a single-property task) was compared with performance on Experiment 1 (a dual-property task). There was no difference in proportion of correct target color response, or in incidence of non-display color or non-target color errors. Thus, the pattern of errors found in Experiment 1 is not due to an age related change in errors associated with dual-property performance.

CHAPTER 4: GENERAL DISCUSSION

Experiment 1 suggests that selective attention affects the formation of illusory conjunctions in young and elderly adults. In young adults illusory conjunctions are more likely to be formed within the attentional window. The elderly are just as likely to form illusory conjunctions inside and outside the attentional window. Experiment 2 demonstrated that the results of Experiment 1 were not due to the dual property nature of Experiment 1. The pattern of illusory conjunctions was similar whether the requirements of the task were to identify two or one properties of the target letter. These findings suggest that age related differences in selective attention may be in part due to an increase in susceptibility to illusory conjunctions outside of the attention window with age. There are a number of possible explanations for these results.

It may be that the elderly are less able to selectively attend to part of the display. Where young adults may successfully accomplish the digit-matching task by adjusting their window so as to only pay attention to the cued attentional window, the elderly adults may have spread their attention to encompass the entire display during both the narrow and wide attentional conditions. Or perhaps the elderly were unable to focus their attention solely on the stimuli in the narrow attentional window because they are more vulnerable to attentional capture from sudden onset of a stimulus than the younger adults (Pratt & Bellomo, 1999). Pratt and Bellomo found that older adults are more likely to pay attention to an irrelevant stimulus that is abruptly presented in the periphery of a display. In either case the elderly are unable to ignore the stimuli presented outside of the narrow attentional spotlight. Consequently, those stimuli were available for illusory conjunction formation, resulting in a greater susceptibility to illusory conjunction outside the visual field. These explanations are also consistent with the literature that suggests that elderly adults are less able to ignore irrelevant information (Hasher & Zacks, 1988; Klein, Pond, Houx, & Jolles, 1997).

A third explanation for the age differences reported in the present experiment is that the differences are not due to an age related attentional difference but to an age related difference in the ability to ascertain the location of the stimuli. Although there is sufficient evidence in the literature that illusory conjunctions are more likely between adjacent stimuli in young adults there is little research that addresses this effect in the elderly. There is, however, evidence that the elderly are not as able as young adults to locate the position of stimuli (Madden & Plude, 1993; Plude & Hoyer, 1986). If illusory conjunctions are more common among adjacent items, and elderly adults have difficultly locating the position of a stimulus, then perhaps the illusory conjunction location effect seen in the young will not be evidenced by the elderly.

Thus, the selectivity aspects of attention may be compromised with age. Age differences are not necessarily due to the dual nature of a task, but also to the flexibility of attention, and perhaps to the older adults' inability to determine the location of an object.

Relevance to Aging Literature

The results of this study are relevant to findings reported in the aging literature. The present research suggests one possible reason why complex tasks are more difficult for the elderly. More complex visual search tasks often require constructing a display wherein formation of illusory conjunctions is possible. For example, in complex visual search tasks completion of the task requires integration of features. In a simpler task only identification of features is necessary. Hence, it is possible that one of the reasons that elderly performance is impaired in more complex tasks is because the elderly are more susceptible to illusory conjunctions.

Also, the above results suggest that older adults' decreased ability to ignore irrelevant information may have another consequence. Since the elderly are less able to ignore irrelevant information, it is possible that irrelevant information presented outside of the attentional spotlight might make more stimuli available for the formation of illusory conjunctions -- resulting in a greater susceptibility to illusory conjunctions outside the attentional spotlight. This might partly account for the greater number of illusory conjunctions found outside the attentional spotlight in the present research.

Developmental Change Issues

There is some question as to whether the results of this experiment actually measure a developmental change and what those developmental changes might reflect. In particular, do the results represent a change in the attentional systems that occur as part of the aging processes, or are there other explanations for the performance differences of the two age groups? The elderly subjects who participated in the present experiment were a high functioning group of elderly adults. Other potential subjects were unlikely to volunteer to participate in this experiment. Hence, this experiment was a comparison of young college students with high functioning elderly adults. Consequently, the argument could be made that the results are true only for high functioning adults. It is likely that participation of all levels of functioning elderly would increase the age differences. Therefore, by studying high functioning adults the impact of aging on the frequency of illusory conjunctions might be underestimated in this experiment. However, it is difficult to tell how much the results would differ. One measure of level of functioning is the WAIS. And when the effects of the two WAIS subscales were factored out of the results using an analysis of covariance there was still an age effect. Moreover, analyses of differences between the top and bottom third of WAIS performers within the elderly group showed no differences in the absolute number of binding errors and the pattern of binding errors. Thus within the elderly intellectual differences did not seem to have an impact. The interesting finding was that the same analyses performed on the young adult data showed that HIGH functioning adults were more likely to make binding errors at the BE condition when attention was narrowed that when there was a wider attentional window.

The data do not reflect a biased sample of elderly adults, but the inclusion of some very high functioning college students. Therefore other factors than age changes in intellectual performance must have contributed to the age differences.

Peripheral vs. Central Processing

One of the most pervasive questions in the aging literature is whether age differences can be attributed to peripheral or to central processes (Norman & Bobrow, 1975.) Therefore, it is reasonable to ask the question, are age differences found in the present experiment due to age-related attentional changes or to age-related changes in peripheral processes? In the present experiment there are a number of peripheral age changes related to the visual system and psychomotor skills that could have affected the results. Of relevance to the present experiment, the elderly visual system is susceptible to an overall decrease in visual acuity, decreased contrast sensitivity, and various ocular diseases which might affect visual acuity. In the present experiment, to control for an age-related decrease in visual acuity, each subject was screened for visual acuity and only participated if he or she had 20/30 vision or better. Also, of particular importance to the present experiment is that the elderly typically experience diminished visual acuity in their peripheral vision (Cerella, 1985). However, the results of the present study suggest that the elderlys' ability to identify the letter does not decrease the further it is from fixation because there was no overall effect of location for letter identification for the elderly (i.e., letter identification accuracy was similar at each pair location.) And in the present experiment another measure of target letter identification accuracy is *tl*. Recall that this parameter, calculated using multinomial modeling, measures the probability that each subject identifies the target letter correctly. Statistical analysis of the *tl* parameter yielded no effect of location, which also suggests that the elderly did not have more difficulty perceiving the letters in the periphery. Lateral masking may also affect older adults' ability to perform the task to a greater degree than the younger adults'. It is possible that the location of the digits in the digit task masked adjacent display items to a greater extent for the elderly.

However, the results suggest that this is not the case because there was no effect of target/distractor pair location on letter identification for the elderly in either the narrow or wide condition. Another peripheral process that may have affected the results of the present experiment is that psychomotor skills are affected with age. In the present experiment the elderly response time was longer than the young adult response time. The increased time that it takes for the elderly adult to respond increases the time that the response must be stored in memory. It is possible this delay increases the older adults' error rate because older adults have more of an opportunity for the memory trace to degrade. But there is no evidence that the degradation in response time could account for age differences in the pattern of responding. There is little doubt that, in general, the elderly have compromised peripheral processing. However, in the present experiment the age differences in peripheral processing do not appear to completely account for the age differences in the findings.

Relevance to Current Theories of Object Perception

An important issue at the core of the development of theories of object perception (see above; Wolf, 1998, 1994; Briand & Klein, 1987; Treisman & Sato, 1990; Duncan & Humphreys, 1989) is whether object perception is a top-down or bottom-up process. Recently Madden, Whiting, Cabeza, & Huettel (2004) suggested that the elderly are able to maintain top – down attentional control and that age differences in visual search are due to bottom up attentional control. Where top – down attentional control is guided by the subject's goals and expectation and the bottom – up attentional control is dictated by the perceptional attributes of the items in the display. Application of this notion to the present findings suggest that elderly impairment would be due to illusory conjunctions, attentional capture, etc. rather than the allocation of attention. Although the above research does not provide supporting evidence exclusively for age differences in either mechanism it does suggest that the age differences might be accounted for by the perceptual attributes of the display and not the attentional manipulation. It would be useful to further examine age difference in these two mechanisms of visual search.

The above results are inconclusive with respect to whether FIT (Treisman & Gelade, 1980) or the Location Uncertainty Principle better describe the mechanism behind the formation of illusory conjunctions. Recall that ‘free floating features’ within and without the attentional window provide support for FIT. And the location uncertainty principle posits that the incidence of illusory conjunctions is determined solely by the location of the target/distractor pair regardless of attentional allocation. In the present research the weak effects of location within (and outside of) the attentional window, support the notion of ‘free floating features’. In both the young and the older adult data there was no difference in the number of illusory conjunctions within the attention window. That is, comparison of location pairs located within the attentional window (that is, location pair CD and EF in the wide attention window condition) exhibited no difference in occurrence of illusory conjunctions. And there was no difference in the number of illusory conjunction outside the attentional window. The notion of ‘free floating features’ is consistent with FIT. However, overall effect of location and a location x window interaction (using both multivariate and multinomial analyses) provide evidence that the number of illusory conjunctions might be partly due to the location of the pair. This would suggest that illusory conjunctions were more likely when the subject was unaware of the location of the object in space. And the location uncertainty principle would provide a better explanation of the formation of illusory conjunctions.

Future research

Because this experiment highlights some perceptual factors influencing attentional control that both differentiate young and older adults and contribute to illusory conjunction effects one possible line of future research would be to examine whether or not elderly adult susceptibility to illusory conjunctions increases as the proximity of the target and distractor increases. Although there is evidence that young adults exhibit a location effect it is not clear that the elderly exhibit a location effect. Directly measuring the location effect in the elderly would be useful.

Another possible avenue of research would be to design an experiment that disentangles the location effect from the attentional effect. This could be accomplished using a design similar to the Prinzmetal, Ivry, Beck, and Shimizu (2000; explained above) where the target and the distractors were equidistant from fixation. In this design the attentional window was manipulated without altering the distance to fixation. Thus, a comparison of age effects using this sort of experimental design would be useful.

In conclusion, illusory conjunctions may partly explain the differences in young and elderly performance on complex visual tasks. Further examination of illusory conjunctions and attention in the elderly is needed to determine the conditions under which illusory conjunctions affect elderly performance.

Appendix A

Comparison of 2 and 21 Target Data Set

tcolorltletter. An ANOVA was used to compare tcolorltletter responses on 4 and 21 target set conditions. The between subject variables were age (young, old) and condition (4 vs. 21) and the repeated measures were attentional window size (narrow, wide) and target pair location (CD, BE, AF). This analysis yielded no significant effect of condition and no significant effect of any of the two, three or four-way interactions with condition. Also, there was no significant two, three or four-way interaction with age.

ocolorltletter. An ANOVA was used to compare non-display color errors given that the target letter was correct in the 4 target condition with the 21 target condition. As in the previous analysis, the independent variables were age (young, elderly), pair location (CD, BE, AF), attentional window size (narrow, wide), and condition (4, 21). The dependent variable was the proportion of non-display color errors. The analysis yielded no significant main effect of condition. In addition, there were no statistically significant two, three, or four-way interactions involving condition. There was also no significant two, three, or four-way interaction involving age.

ncolorltletter The conditional probability, ncolorlletter, was compared in the 4 and 21 target data using an ANOVA. The independent variables were age (young, older), condition (4, 21), attentional window (narrow, wide), and pair location (CD, BE, AF). The ANOVA yielded no significant difference in condition and no significant two, three or four-way interaction involving condition (including those involving age and condition).

Appendix B

ICE
Instructions to the Participant
(21 letter, both condition)

In this experiment you will be asked to do two tasks. The first and most important task is to determine whether two digits that appear on the screen are the same or different (SHOW PARTICIPANT EXAMPLE OF THE DISPLAY). The second task is to determine the color and identity of a target letter.

The display will appear for only a brief time. First, a plus sign and two asterisks will appear on the screen. Please look at the middle plus sign and spread your attention to the outer asterisks. The two outer asterisks will cue you as to where the digits will appear. It will make the task easier if you spread your attention to the asterisks. The digits will always appear in the cued locations. Next, the two digits will appear, and then a target letter and a distractor will appear on the screen. The distractor will always be an “O”. The target letter can be any other letter on the keyboard.

Your first task is to determine whether the digits matched. If the digits did match press the key labeled “match” on the keyboard, if the digits did not match press the key labeled “mismatch”. Next report the color of the target letter. If the letter was blue press the key labeled “blue”. If the target letter was red press the “red” key. If the target letter was green press the “green” key. And if it was purple, press the key labeled “purple”. And last determine the identity of the target letter. Press the key on the keyboard corresponding to the identity of the target letter.

Please answer as quickly and as accurately as possible. Remember the most important task is the digit-matching task.

Any questions?

Appendix C

Probability of each Response – 21 target condition

$$
\begin{aligned}
P(CT) = & (tl * tc * nc * \alpha) \\
& + (tl * tc * (1\text{-}nc) * \alpha) \\
& + (tl * (1\text{-}tc) * nc * \alpha * 0.33) \\
& + ((tl * (1\text{-}tc) * (1\text{-}nc) * 0.25)) \\
& + ((1\text{-}tl) * tc * nc * \alpha * 0.05)) \\
& + ((1\text{-}tl) * tc * (1\text{-}nc) * \alpha * 0.05) \\
& + ((1\text{-}tl) * (1\text{-}tc) * nc * \alpha * 0.05 * 0.33) \\
& + ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.05 * 0.25))
\end{aligned}
$$

$$
\begin{aligned}
P(CT) = & (tl * tc * nc * (1\text{-}\alpha)) \\
& + (tl * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.33) \\
& + (tl * (1\text{-}tc) * nc * (1\text{-}\alpha)) \\
& + ((tl * (1\text{-}tc) * (1\text{-}nc) * 0.25) \\
& + ((1\text{-}tl) * tc * nc * (1\text{-}\alpha) * 0.05)) \\
& + ((1\text{-}tl) * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.05 * 0.33) \\
& + ((1\text{-}tl) * (1\text{-}tc) * nc * (1\text{-}\alpha) * 0.05) \\
& + ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.05 * 0.25))
\end{aligned}
$$

$$
\begin{aligned}
P(CO) = & (tl * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.33) \\
& + (tl * (1\text{-}tc) * nc * \alpha * 0.33) \\
& + (tl * (1\text{-}tc) * (1\text{-}nc) * 0.25) \\
& + ((1\text{-}tl) * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.05 * 0.33) \\
& + ((1\text{-}tl) * (1\text{-}tc) * nc * \alpha * 0.05 * 0.33) \\
& + ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.05 * 0.25)
\end{aligned}
$$

$$
\begin{aligned}
P(IT) = & ((1\text{-}tl) * tl * tc * nc * \alpha * 0.95)) \\
& + ((1\text{-}tl) * tc * (1\text{-}nc) * \alpha * 0.95) \\
& + ((1\text{-}tl) * (1\text{-}tc) * nc * \alpha * 0.95 * 0.33) \\
& + ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.95 * 0.25))
\end{aligned}
$$

$$
\begin{aligned}
P(IN) = & ((1\text{-}tl) * tl * tc * nc * (1\text{-}\alpha) * 0.95)) \\
& + ((1\text{-}tl) * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.95 * 0.33)
\end{aligned}
$$

$$+ ((1\text{-}tl) * (1\text{-}tc) * nc * (1\text{-}\alpha) * 0.95)$$
$$+ ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.95 * 0.25))$$

$$P(IO) = ((1\text{-}tl) * tc * (1\text{-}nc) * (1\text{-}\alpha) * 0.95 * 0.33)$$
$$+ ((1\text{-}tl) * (1\text{-}tc) * nc * \alpha * 0.95 * 0.33)$$
$$+ ((1\text{-}tl) * (1\text{-}tc) * (1\text{-}nc) * 0.95 * 0.25))$$

Appendix D

Mean Reaction Time for Color Responses

Mean Reaction Time for Color Responses at each Pair Location in the Narrow and Wide for each Age Group

Young Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
letter correct	2091	2403	2420	2305	2540	2365	3805	2903
tcolor[a]	1920	1674	1665	1753	1883	1762	1714	1786
ncolor[b]	2153	2241	1776	2057	1917	1797	1691	1801

Elderly Adults

	Narrow				Wide			
	CD	BE	AF	Total	CD	BE	AF	Total
letter correct	3233	3009	3152	3131	3493	3375	3198	3355
tcolor[a]	2377	2225	2097	2233	2213	2318	2315	2282
ncolor[b]	2352	2146	2599	2366	2315	2176	2436	2309

[a] target color correct and letter correct

[b] distractor color and letter correct

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