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Age Differences in Skill Acquisition with Conjunction Search

by

Geoffrey Ho

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Abstract

Ten younger and ten older adults were provided with consistently-mapped (CM) training on a conjunction search task for 16 sessions. After every fourth sessions, the target and a distractor were reversed. Results indicated that after training, on target-present trials, display size slopes for reaction time and fixation number were near zero for both age groups. However, on target-absent trials, older adults continued to show significant display size effects. Moreover, no age differences were found in disruption upon reversal and non-specific positive transfer was evident for both age groups. Neither the priority-learning deficit hypothesis nor the generalized slowing hypothesis provides adequate explanations for the data. Instead, it is suggested that older adults may be exhibiting more cautious behaviour when searching on target-absent trials. Transfer data suggest the possibility of rule-based learning in skill acquisition in visual search.

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Introduction

One of the more important types of skill acquisition is perceptual learning, the ability to associate a perceptual stimulus with a task-related response. There are benefits from practice on perceptual learning tasks such as random-dot stereograms (Sowden, Davies, Rose, & Kay, 1996) and hyperacuity (Kumar & Glacer, 1993). Most pertinent to the present work, in younger observers, visual search skills have been shown to improve with practice (Schneider & Shiffrin, 1977; Wolfe, Cave, & Franzel, 1989).

The effect of practice on visual search among older adults is less clear. Some researchers have demonstrated that when people are trained on a semantic category visual search task, training is less effective for older adults than younger adults (e.g., Fisk and Rogers, 1991). Others have shown no age differences in asymptotic levels of performance using a more traditional visual search task (e.g., Anandam & Scialfa, in press). Thus, it remains unclear whether practice is less effective for older adults, and if so what are cognitive mechanisms behind this deficit? Fisk and his colleagues suggested that older adults might have difficulties in attending to the target, whereas others have argued that generalized slowing can explain these findings.

The present study attempted to answer some questions associated with the problems above. First, will age differences in perceptual learning be evident when performing a conjunction search task? Second, how will repeated reversal and transfer conditions affect age differences in performance? Last, can the inclusion of eye movement data provide additional information regarding search that is not evident when using RT alone?

Visual Search

Visual search involves the detection, localization and identification of a small number of targets (usually one) when placed in a group of distractors. For example, the target might be a white line oriented to the right, embedded in distractors of differing luminance contrast and/or orientation. Search is affected by a variety of factors, including the complexity of the stimuli, their location in a display, the display size (i.e., the number of items in the display), and the age of the observer. Several theories have been proposed over the last two decades to account for these effects.

Feature integration theory (FIT; Triesman & Gelade, 1980) was the first contemporary model of visual search. According to FIT, searches can be separated into two dichotomous types, feature search and conjunction search. In feature search, the target and distractors differ along a single perceptual dimension (e.g., colour). Information in feature search displays is processed preattentively and in parallel; the target is detectable at a glance with no effort or searching involved such that the target appears to "pop-out". As a result, performance is often independent of the number of items in the display. In contrast, in conjunction search, the stimuli are defined along two or more dimensions (e.g., colour and orientation), and the target shares feature values of at least one of these dimensions with every distractor. In order to find and identify the target (when it is present) in this type of display, FIT holds that search requires serial, self-terminating processing of all items (Triesman & Gelade, 1980).

Although FIT was able to account for a considerable amount of data (for reviews see Triesman & Gormican, 1988; Triesman & Souther, 1985), several findings pose difficulty for the model. For instance, some feature searches can produce display size effects similar to conjunction search (Triesman & Gormican, 1989; Scialfa, Esau, & Joffe, 1998), some conjunction searches show flat display size slopes similar to feature search (Humphrey & Kramer, 1997) and some conjunction searches do not show a target-absent to target-present slope ratio of 2:1 as predicted from the serial, self-terminating search (Friedman-Hill & Wolfe, 1995; Wolfe, et al., 1989). Moreover, several studies have shown that with practice, display size effects can be reduced considerably (Schneider & Shiffrin, 1977; Wolfe et al., 1989), suggesting that in many cases, displays that typically generate a serial search can be processed in parallel.

The acquisition of this level of proficiency has not been accommodated explicitly by either FIT, or other theories of visual search (e.g., Wolfe et al., 1989; Duncan & Humphreys, 1989) but is central to models of automaticity and skill development, several of which are strength theories. They posit that the development of skill involves the strengthening of connections associated with performing a task (e.g., Anderson, 1982; MacKay, 1982; Schneider, 1985). These connections can be neural activation produced by the stimuli or stimulus-response associations. These theories, however, differ in the mechanism that is being modified. The most influential theory in practice and visual search is a connection system model, which suggests that connection weights store knowledge and it is these weights that are modified with practice (Schneider, 1985; Schneider & Detweiler, 1987).

Skill Acquisition in Visual Search

In a now classic set of studies, Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977) trained participants on a hybrid memory/visual search task. In this task, participants are provided with one or more targets to memorize and subsequently, a search display is presented in which participants are to search for the previously memorized targets. The participants were also trained using either a consistent mapping (CM) or a varied mapping (VM) technique. In CM training, the targets and the distractors in the display were fixed and did not change over trials. For example, in Schneider and Shiffrin's (1977) first experiment, participants in the CM condition were asked to search for specific digits in a display that contained both digits and letters. In contrast, in VM training, the target and distractors were frequently interchanged.

Schneider and Shiffrin (1977) found that when participants performed CM training, their performance improved, and memory size and display size effects declined. Moreover, performance in CM training eventually became so proficient that the display size effect were eradicated as evident in near-zero slopes. That is, reaction times remained constant regardless of display size. This flat slope indicated to Schneider and Shiffrin (1977) that performance had become automatic. For VM training, the results were markedly different. The general improvements with practice were evident in easier VM conditions, but not in more difficult ones. In addition, there was still evidence of significant memory and display size effects, and performance never reached the point of automatic processing.

To account for these results, Schneider and Shiffrin (1977) argued that in VM training, participants were using what they called controlled search to locate the target. A controlled process is under the attentional control of the individual. It is limited to the capacity of the short-term memory store such that only a few nodes may be activated in parallel. Therefore, in VM training, participants must use an effortful, time-consuming process that is at least partially serial in nature to locate a target.

In contrast, in CM training, processing moves from controlled processing to what they called automatic processing. In automatic processing, the mere presentation of certain stimuli will activate long-term memory with minimal effort or attention. Automatic processing is thus faster and is not limited to any attentional capacity. However, because automatic processing is considered to be a relatively stable set of connections, it is difficult to suppress, change, or ignore (Schneider & Shiffrin, 1977). Schneider (1985) discussed in greater detail the steps involved in the development of automaticity.

Strength Theory of Automaticity

Evolving on the work from Schneider and Shiffrin (1977), the strength theory of skill acquisition (Schneider, 1985) argued that long-term memory consisted of a network composed informational elements. Practice involves the strengthening of transmissions between these elements. When learning a task, there are two main types of learning in the development of automatic processing, associative learning and priority learning. Associative learning involves learning the relationship between one particular message and another when the two messages co-occur frequently. Messages can be visual stimuli, responses, or memory units. For instance, in most visual search experiments, the pressing of a "present" key once the target is detected and identified is an example of associative learning.

Priority learning is the modification in the strength of messages that are being transmitted such that messages that are important to the task receive more strength, whereas unimportant messages receive less strength. At the onset of visual search, comparisons between each item and the target memory set takes place in order to identify the target. After each hit or correct rejection, priority learning modifies the object's attention-attraction strength, the amount of activation a stimulus produces to initiate a response to the item. If the object is the target, more attention-attraction strength will be assigned, whereas if it is a distractor, less attention-attraction strength will be assigned. If this modulation of attention-attraction strength is sufficient, then the target automatically attracts attention before all other items in the display and performance becomes independent of load (e.g., display size). This results in the "pop-out" effect described in several visual search studies.

Strength theory argues that the transition from controlled to automatic processing, via priority and associative learning occurs only during CM training. In VM training, while associative learning may occur, priority learning is not allowed to occur because both the target and the distractor are continually reversed, and thus the target's relative attention-attraction strength does not increase.

Theories of Age Differences in Skill Acquisition

While the research and theory described above has been developed to explain skill acquisition in the young, others have tried to extend this work to explain performance in the elderly. A consistent finding in the gerontological literature is that older adults perform comparably to younger adults in easy feature search, both groups demonstrating trivial display size effects (but see Scialfa, Esau, & Joffe, 1998). However, in most conjunction searches, an increase in the number of distractors more deleteriously affects older adults than younger adults (Plude & Doussard-Roosevelt, 1989; Foster, Behrmann, & Stuss, 1995; Scialfa & Joffe, 1997) although this is not always the case (e.g., Humphreys & Kramer, 1997).

The reason for this impairment is the subject of debate. Rabbitt (1965) concluded that older adults were less able to ignore irrelevant information, and thus longer reaction times were the result of discrimination difficulties between relevant and irrelevant features of stimuli. Cerella (1985) suggested that older adults perform comparably to younger adults, but that there exists a global reduction in speed of performance in all tasks. Another explanation is that age differences in search may be the result of spatial localization deficits in older adults (Plude, 1990). Plude and Doussard-Roosevelt (1988) demonstrated that when the elderly were provided with cues that limited the spatial area to be attended, display size effects were eliminated. Still others have demonstrated that search is impaired for older adults because they possess a reduced useful field of view (UFOV) and thus are not able to quickly process information outside of central vision (Ball, Beard, Roenker, Miller & Griggs, 1988; Scialfa, Kline, & Lyman, 1987; Scialfa, Thomas, & Joffe, 1994). For example, when target-distractor similarity is high, the UFOV is reduced (Scialfa et al., 1987). Although reduction of the UFOV occurs for all adults, the reduction is more pronounced for older adults (Ball et al., 1988).

Search efficiency does improve with practice for older adults. However, some studies have found age differences even after extensive practice. Fisk and Rogers (1991) trained younger and older participants in a pure visual search task, a pure memory search task, or a hybrid visual/memory semantic category search task. In a semantic category search task, participants are given a superordinate category as a target (e.g., fruit). They are then shown a display, wherein a word in the display may be a subordinate object in the target category (e.g., apple). If participants see a word that belongs in the superordinate category, they respond "target-present". Their results indicated that younger and older adults performed comparably in the memory search task. However, older adults showed significantly greater display size effects in both the pure visual search task and the hybrid memory/visual search task. Arguing from strength theory, they hypothesized that older adults were either impaired in categorization (which was a component of associative learning in this task) or priority learning. However, because older adults showed greatest impairment in the pure visual search task, which is assumed not to involve any categorization, they concluded that the elderly likely have deficits in priority learning. This was termed the priority-learning deficit hypothesis.

Since this study, several subsequent researchers have arrived at similar conclusions, employing a reversal condition, wherein target categories and distractor categories were interchanged after training participants on a semantic category task. Based on the assumption that an automatic response is difficult to ignore, modify, or suppress (Schneider & Shiffrin, 1977), performance at reversal is used to measure the degree of automatic processing developed. If an individual is given a task that is contrary to the automatic response, there should be a disruption in performance of the task as a result of failure to suppress the automatic response.

For example, Fisk, Hertzog, Lee, Rogers, and Anderson-Garlach (1994) provided training for older and younger adults in a visual search task. A reversed display was presented to the participants after training. To control for individual differences with speed that might mask age differences at reversal, disruption scores were calculated in the following manner: (Reversal RT - Final Training RT/ Final Training RT). The younger adults showed significant disruption (49% disruption), whereas little disruption was observed in older adults (16% disruption). This led Fisk et al. (1994) to conclude that younger adults developed the visual search task to a point of automaticity, whereas the older adults did not benefit to the same extent.

The reversal of the target and distractors can be used to further examine the type of transfer from one task to another. Transfer refers to the degree with which the skills of one task generalize to the skills of another task. Transfer can be positive, (i.e., it can aid the performance of another task) or negative, (i.e., it is detrimental to the performance of another task). For instance, when a target and a distractor are switched, and it causes disruption in performance, this is considered to be negative transfer. However, if after reversal, performance improves quickly relative to initial learning, positive transfer is inferred.

Transfer can also be stimulus-specific or non-specific. Stimulus-specific transfer is defined as positive transfer that occurs only if the stimulus presented in a task was identical to the stimulus presented in a previous task. In contrast, non-specific transfer suggests generalization of a stimulus to a different stimulus. Studies supporting both stimulus-specific and stimulus-nonspecific transfer have been reported. Kramer et al. (1997) performed two studies examining transfer on a Sternberg memory search task. They found that transfer was neither stimulus-specific nor rule-specific. That is, positive transfer at reversal was evident after training participants using specific stimuli. As well, positive transfer was also evident after training participants using one set of rules and then presenting them with a new but similar rule at reversal. That is, modifications of the rules at reversal did not disrupt performance. Ahissar and Hochstein (1997) however, have found that transfer can be either stimulus-specific or nonspecific, depending on the difficulty of the task. They gave their participants a visual search task and found increasing stimulus-specific transfer when the targets and distractors were more similar.

Older adults have also been reported to exhibit less transfer when reversal is not stimulus-specific. Fisk, Rogers, Cooper, & Gilbert (1997) trained both younger and older participants in a semantic category task. After training, all participants underwent one session in a transfer condition, but participants were shown the same words as in training, new words that were in the trained semantic category, and a new set of words which were part of a new semantic category. The results indicated that younger adults who received new words that were still in the trained semantic category performed better than with completely new words in a new semantic category. Older adults showed no performance differences between these conditions. This indicated that only younger adults were able to transfer the knowledge gained during training to generalize to other instances of the semantic category.

Not all studies have found age deficits in the development of automaticity including earlier work that suggested that older and younger adults benefit equally from practice (e.g., Madden & Nebes, 1980). More recently, Anandam and Scialfa (in press) postulated that the age difference in display size effects found in their data might have been the result of an age reduction in the UFOV (Ball, et al., 1988; Scialfa, et. al, 1987). That is, a number of researchers have suggested that as a result of aging, the size of one's visual attentional window is reduced, such that it will lead to more difficulty attending to more peripheral events (Ball, et al., 1988; Scialfa, et. al, 1987). Anandam and Scialfa (in press) found that after accounting for the UFOV, there were no age difference in display size effects, suggesting the possibility that age differences in skill acquisition may be limited to less central areas of a display.

Similarly, Scialfa, Jenkins, Hamaluk and Skaloud (in press; Experiment 2) trained participants using a CM procedure on a conjunction search task while eye movements were recorded. They found no age differences in the rate of improvement for acquiring conjunction search skills. Fixation number did not differ with age and fixation data from both younger and older adults indicated that attention was directed to objects that shared the target's luminance contrast, suggesting no age differences in feature-based selection. If the priority-learning deficit hypothesis is correct, older adults should have had more difficulty fixating target-like objects. In addition, a reversal condition was presented to the participants. According to the priority-deficit learning hypothesis, older adults should not reach automatic levels of processing and thus should show less disruption in performance at reversal. However, once again, older and younger adults were equivalently disrupted, suggesting that both age groups reached equivalent levels of proficiency during training.

Why are there conflicting results in research on age differences in acquiring search skills? The results from Fisk, Rogers, and their colleagues suggest that older adults are impaired in priority learning, whereas Scialfa and his colleagues suggested that age differences do not exist or are the result of something other than a deficit in priority-learning. The discrepancy may result from at least two critical differences in the methods employed across the studies.

First, Anandam and Scialfa (in press) and Scialfa et al. (in press) used traditional visual search tasks. That is, the participants were told to look for a single target, and to respond "present" if the target was detected, and "absent" if the target was not detected. In comparison, many of the studies performed by Fisk and his colleagues have focused on semantic category tasks (Hertzog, Cooper, and Fisk, 1996; Fisk & Rogers, 1991; Fisk et. al., 1997; Rogers, Fisk, & Hertzog, 1991). Semantic categorization involves both searching and matching a word with its superordinate category and thus, the task is more cognitively demanding and places a greater load on primary memory than a pure visual search task. Because the elderly have difficulties with word categorization (Kutas & Iragui, 1998) and word retrieval associations (for review, see Mackay & Abrams, 1996), this may account for the age deficits previously reported.

Another possible difficulty with many studies investigating age differences in visual search acquisition is in design. Many of the studies that have found age differences used a within-subjects design wherein the participant was trained simultaneously in both a CM and a VM procedure (e.g., Fisk, McGee, & Giambra, 1988, Experiment 2) mixed among blocks. It is possible that this constant switching between CM and VM training affects older and younger adults differently. That this switching between CM and VM training accounts for the age differences found in these studies would argue against age deficits in visual search (Bailey & Lauber, 1998). Strayer and Kramer (1994) suggest that providing participants with a mixed design may affect participant strategies and thus will raise one's response criterion.

The priority-learning deficit hypothesis has also been challenged by Cerella (1991), who claimed that age differences in skill acquisition could be explained by generalized slowing (Cerella, Poon, & Williams, 1980). Generalized slowing is an extension of the complexity hypothesis (Cerella, Poon, & Williams, 1980) which asserted that slower reaction times for older adults were a function of task complexity. Cerella (1990) argued that tasks are performed in a series of steps and each of these steps is slowed with age. Therefore, a more complex task that requires more steps will necessarily be exponentially slower to complete for an older adult. It argues that this slowing factor is the result of a central processing deficit that occurs naturally with age.

The theory asserts that RTs of older adults can be very well predicted from those of younger adults by using either a simple linear or power function. This prediction has been borne out on a variety of cognitive tasks (Cerella, 1985; Myerson, Wagstaff, & Hale, 1994) suggesting that all information-processing tasks are equivalently slowed as normal aging occurs.

The vast majority of the research conducted to support generalized slowing has involved regressing the RTs of older adults against the RTs of younger adults and using Brinley plots to illustrate the relationship (Brinley, 1965). Typically, a very strong (commonly $r^2 > .90$) linear relationship is observed. Moreover, the slope estimates for the linear function are commonly in a area of 1.5, suggesting that older adults are approximately 50% slower in their rate of information processing (Hale & Myerson, 1995).

Cerella (1991) argued that the results presented in Fisk and Rogers (1991) could be accounted for by generalized slowing. A Brinley analysis accounted for 93% of the data for Fisk and Rogers' (1991) Experiment 1, for 97% of the variance in their Experiment 2, and for 99% of the variance in Experiment 3.

Fisk, Fisher and Roger's (1992) rebutted Cerella's (1991) argument by demonstrating Brinley plots are not the best measures to account for slowing. Fisk et al.

(1992) created two hypothetical sets of data. In the first set, the performance of younger and older adults was equal. In the second set, older adults were twice as slow as the first set. A Brinley analysis of the combined data was able to account for 97.3% of the variance, but did not show the differences between the two sets of data. They argued that even though other models may only account for very little more of the data, they revealed critical information that Brinley analyses failed to show.

Similarly, other studies have questioned the acceptability of generalized slowing. Scialfa and Joffe (1997) demonstrated that when eye movement data are subjected to Brinley analyses, the regression for fixation number has a comparable slope to reaction time. However, generalized slowing argues that age deficits are the result of only processing speed differences. Thus, it provides no explanation for why fixation number, which does not measure processing speed, should have this result.

The Present Study

The present study investigated the predictions of the priority-learning deficit and generalized slowing hypothesis. Participants were trained on a pure visual search task and were given not just one, but three reversals throughout the training period. The present study also included eye movement data along with global RT to analyze search performance.

The inclusion of eye movement data, provides additional information to gain a better understanding of search processes. For instance, in a search paradigm a reaction time of 600 msec may reflect three fixations at 200 msec each, or two fixations of 300 msec each (Scialfa and Joffe, 1998; Zelinsky & Sheinberg, 1997). In the first situation, more overt searching is performed, but less time is employed for processing stimuli, whereas in the latter situation, the reverse is true.

Eye movement data has also been shown to be able to differentiate between serial and parallel search. Williams, Reingold, Moscovitch, & Behrmenn (1997) found that more fixations were made during serial search, and there was an interaction between target-presence and type of search in latency to move (i.e., first fixation duration). Scialfa et al. (in press) showed similar differences in fixation number. If the development of automaticity in search involves the transition from serial to parallel search, then this should be reflected in the eye movement data. In the strongest case, automaticity will be reflected in RTs and fixation number that are independent of display size.

Eye movements can also demonstrate the feature-based selectivity that directs search. That is, it is posited by some models of visual search, (e.g., Guided search, Cave & Wolf, 1989) that parallel processing of features in a display guide attention to be directed to specific items. This type of feature-based selectivity can be analyzed by examining which objects the majority of fixations are landing on (Scialfa & Joffe, 1998; Scialfa et al., in press). In the present study, feature-based selectivity was indexed by the selection factor (Scialfa & Joffe, 1998; Scialfa et al. in press) which is a ratio of fixations that land on objects that share the target's luminance contrast over the total number of fixations that land on any object.

Using eye movement data to accompany RT, a number of the hypotheses made by the priority learning deficit hypothesis and generalized slowing can be tested, as summarized in Table 1 and 2. According to strength theory, CM training will result in a transition from controlled processing to automatic processing, and this should be reflected in

Table 1. Hypotheses for older and younger adults for each dependent variable after initial practice according to strength theory and generalized slowing.

Dependent Measure	Strength Theory	Generalized Slowing
Young RT	Decrease	Decrease
Old RT	Decrease (Less)	Decrease (Less)
Young Fixation Duration	Unspecified	Shorter Fixations
Old Fixation Duration	Unspecified	Shorter Fixations (Greater)
Young Fixation Number	Fewer Fixations	Unspecified
Old Fixation Number	Fewer Fixations (Greater)	Unspecified (Equivalent)
Young Selection Factor	Bias target	Unspecified
Old Selection Factor	Bias target (Less)	Unspecified (Equivalent)

Note. Parenthesized words refer to the effect among older adults relative to younger adults. (Less) means older adults will have a lower value on the dependent variable, (Equivalent) means the predicted effect will be equal for the two age groups, and (Greater) means the older adults should have a higher value on the dependent measure.

Table 2. Hypotheses for disruption scores in older and younger adults for each dependent variable according to strength theory and generalized slowing.

Dependent Measure	Strength Theory	Generalized Slowing
Young RT	Increased RT	Increased RT
Old RT	Increased RT (Less)	Increased RT (Equivalent)
Young Fixation Duration	Unspecified	Longer Fixations
Old Fixation Duration	Unspecified (Less)	Longer Fixations (Equivalent)
Young Fixation Number	More Fixations	Unspecified
Old Fixation Number	More Fixations (Less)	Unspecified (Equivalent)
Young Selection Factor	Decreased Bias To Target	Unspecified
Old Selection Factor	Decreased Bias To Target (Less)	Unspecified (Equivalent)

Note. Parenthesized words refer to the effect among older adults relative to younger adults. (Less) means older adults will have a lower value on the dependent variable, (Equivalent) means the predicted effect will be equal for the two age groups, and (Greater) means the older adults should have a higher value on the dependent measure.

parallel search. Therefore, there should be a reduction in the display size effect and also a reduction in the number of fixations. Moreover, with practice, strength theory predicts that attention-attraction strength will increase for objects that share salient target features, thus this should be reflected in an increase in the selection factor variable as training progresses.

The selection factor should differ between older and younger adults according to the priority-learning deficit hypothesis. Older adults are suggested to be impaired in their priority learning which results in less automatic processing. Thus attention is expected to often be directed to a wider variety of distractors, leading to a smaller selection factor value relative to younger adults. Moreover, because older adults are not expected to attain the same degree of automatic processing as younger adults, there should be a significant age difference in display size effects in both RT and fixation number. The predictions for average fixation duration are vague. Schneider (1985) argued that with development of automatization, "the memory-comparison mechanism is eliminated" (Schneider, 1985, p. 487), suggesting that processing speed will increase as a result. However, whether the elimination of the memory-comparison mechanism can be directly mapped by average fixation duration is not known. Zelinsky and Sheinberg (1997) found fixation durations were unrelated to search, however, Scialfa and Joffe (1997) found fixation durations were inversely related to fixation number. As more fixations are made, fixation number is reduced proportionately and this pattern was equivalent for older and younger adults.

In contrast, generalized slowing does not predict any differences in fixation number, but only in the speed of processing. Thus, according to the generalized slowing hypothesis, age differences will only be borne out in RT and average fixation duration. Additionally, no differences are expected in the selection factor, because it is not a measure of processing speed.

Upon initial reversal, strength theory predicts significant disruption in performance that will be reflected in longer RTs, more fixations, and selection biased toward the former target. The priority-learning deficit hypothesis would predict that disruption scores for younger adults will be greater than for older adults, suggesting that automaticity has only been attained by younger adults. However, generalized slowing would argue that older adults will exhibit an equivalent amount of disruption at reversal. That is, although actual amount of disruption for older adults will be greater, relative to their own performance at the end of training, there should be no differences.

The predictions with respect to transfer are less clear. If performance improves quickly after reversal, it can be concluded that this positive transfer results from rule-based learning (Kramer, Strayer, & Buckley, 1997) or a more generalized form of neural activation (Fisk et. al., 1997; Schneider & Fisk, 1984; Sireteanu & Rettenbach, 1995). If learning is slow and difficult after reversal, learning is inferred to be stimulus-specific (Ahissar & Hochstein, 1997; Logan, 1988). Fisk et al. (1997) also found age differences in transfer. While positive transfer was found for younger adults, little or no transfer was found for older adults. Because of the inconsistency of the previous findings, performance after the first reversal and subsequent reversals are exploratory in nature.

Performance on the later reversals will have several theoretical implications. If there is less disruption on later reversals compared to the first reversal, it would suggest some positive transfer. Strength theory accounts for positive transfer by suggesting a spread of activation to other nodes. Schneider and Fisk (1984) provided their participants with a semantic category visual search task. Upon reversal, participants were given new target words but the new words belonged to a previously trained target category. They found that there was positive transfer in the reversal condition suggesting that participants were able to transfer knowledge of the target semantic category. To explain this learning, they suggested that learning specific words in a category must also provide more attention-attraction strength to the node that represents that category feature. Whether this explanation would hold for a pure visual search task is questionable, because it would suggest entire featural dimensions may be transferred.

Positive transfer at reversal may also suggest that a general rule-based strategy of search has been developed such that participants can adapt to changing stimuli (Kramer, et al., 1990). For instance, in a double conjunction search display in which the stimuli's dimensions are colour and orientation, the participant could adopt a subset search strategy wherein they apply the algorithm, ignore objects that do not share the target's colour, and do a parallel search on orientation. This rule-based strategy would enable the participant to find a target efficiently regardless of reversal.

For search theories, such as the Guided Search Model, to account for such a positive transfer, they would have to allow for a much more flexible modification of it's top-down component. In its most current version, Guided Search Model 2.0 (GSM2, Wolfe, 1994), suggested that top-down activation is more flexible than the original version had proposed. Rather than assigning a quantitative activation value to the target (e.g., the target is 20°), Wolfe (1994) suggested that top-down activation is performed along broad categorical channels (e.g., the target is "steep" and "right"). This allows for positive transfer for a target line oriented at 20°, if a new target is a line oriented at 30° because they would activate the same channels but just at different levels. However, in the complete reversal condition as the one provided here, GSM2 would still have difficulty explaining positive transfer, because the trained target and the reversal target are diametrically opposite on one relevant dimension.

Method

Participants

Ten younger adults (M = 23.20 yrs, SD = 3.16 yrs) and 10 older adults (M = 66.20, SD = 2.97 yrs) were recruited from the community and around the University of Calgary to participate in the study. All the participants received $5.00 (CDN) for each session attended and received a bonus of $10 (CDN) for completing the entire experiment. Younger participants had more education (M = 16.1 yrs, SD = 1.2 yrs) than older adults, (M= 13.5 yrs, SD = 2.72 yrs), t (18) = 2.77, p = .013. Because this is a concern that may have confounded results, many analyses were performed with education as an additional independent variable. This will be treated below.

All participants reported good general and visual health. They were screened for acuity and were corrected to 20/20 vision if needed and intraocular pressure was measured to ensure that all participants showed no early signs of glaucoma. Older adults (M = .915, SD = .29) did not differ from younger adults (M = .765, SD = .18) on acuity, t (18) = -1.40, p = .178. As well, intraocular pressure did not differ between older and younger adults, in either the left eye, (Old: M = 15.83 mmHg, SD = 3.79 mmHg; Young: M = 15.55 mmHg, SD = 2.95mmHg), t (17) = .46, p = .655, or the right eye, (Old: 16.39 mmHg, SD = 3.74 mmHg; Young: M = 16.90 mmHg, SD = 3.95mmHg) t (17) = .29, p = .776.

Apparatus

The conjunction search displays were presented on the Eyegaze Development System (EDS) using software provided by LC Technologies, Inc., Fairfax, VA (Cleveland & Cleveland, 1992).[1] The EDS uses a 486 platform to measure eye movements using the pupil center/corneal reflection technique (Young & Sheena, 1975). An LED placed underneath the monitor floods the eye with a low-level infrared light (880 nm). A Sanyo CCD high speed, infrared camera collects the infrared readings at a rate of 30.3 Hz. Stimuli were presented on a 15" Sony Trinitron Multiscan CPD-100 GS. Monitor resolution was set at 640 X 480 pixels at 60Hz.

Optical correction was provided with a R.H. Burton trial lens set. Acuity was measured using Post-Script generated Landolt Cs with eight targets for each level of minimum angle of resolution, which varied in steps of approximately .05 log units. Intraocular pressure was measured using a Reichart NCT II noncontact tonometer. Luminance of the display elements was measured using a Minolta LS 110 photometer.

Stimuli

The stimuli in the search display consisted of white and black line segments that were either oriented 45° to the right or 45° to the left (see Figure 1). Each line was approximately 1.5 min in length. The search display consisted of one target, and two types of distractors. For Sessions 1 - 4 (Training Period 1), and Sessions 9 - 12 (Training

[1] David Stewart provided additional programming to allow presentation and analyses for the present experiment.

Period 3), the target was a white-right line and the distractors were white-left lines, and black-right lines. For Sessions 5 - 8 (Training Period 2) and Sessions 13 - 16 (Training Period 4), the target was a black-right line, and distractors were black-left lines, and white-right lines.

Design

The study consisted of 16 sessions, divided into four training sessions, the latter three involving reversal conditions. Each session had 8 blocks of 30 trials for a total of 240 trials. Each training period was separated into four days of training. After the completion of the Training Period 1, all the participants underwent a conjunction reversal that also provided the onset of Training Period 2. That is, the target was switched to a black-right line, which was displayed with white-right lines and black-left lines. Reversals were provided two additional times such that the same display in Training Period 1 was shown in Training Period 3, and the displays for Training Period 2 were identical to those used in Training Period 4.

Procedure

Prior to the first day of training, all participants provided their informed consent to participate and were then screened for visual acuity and intraocular pressure. They were then given instructions on how to perform the task and were provided with 10 practice trials to ensure that they understood the procedure.

Each block began with a calibration task in which the participant had to visually track a dot that moved around the screen. If calibration was unsuccessful (i.e. the EDS failed to read the participants' movements correctly), the calibration program would attempt to recalibrate locations where recordings were not tracked properly. After three attempts to recalibrate a particular location, the program would reset completely and have the participant recalibrate all locations once again.

Each trial began with a centrally placed black fixation cross on a grey background. Participants were instructed to fixate on the cross at the beginning of each trial and to press any key to initiate the onset of the search screen. The participant's task was to search the display for the target and to respond whether the target was present or absent by pressing the corresponding key on the keyboard. Accuracy feedback was given on the screen; a "plus" sign was if the answer was correct, a "minus" sign if the answer was incorrect, and a question mark was displayed if the observer had not responded in 5 seconds.

The fixation screen appeared for either 50, 100, or 150 msec. This was randomized for each trial to control for anticipatory searching. On one-half of the trials the target was present and target presence was randomized within each block. Display size varied between 6, 12, and 24 items and was also randomized within each block. The viewing distance of 50 cm was fixed by having participants use a chin rest.

Results

Performance was analyzed along six dependent measures: global RT and response accuracy, fixation number, first fixation duration, average fixation duration, and the selection factor. Fixation durations were calculated using a space window of 11 pixels horizontally and vertically using a screen resolution of 480 X 640. That is, a fixation was recorded if one or more eye movement recordings landed within a 11 pixel window. Average fixation durations did not include the first fixation duration because these reflect display encoding and are often quite long (Scialfa & Joffe, 1997). The selection factor was calculated by taking the number of fixations landing on an object that shared the target's luminance contrast, divided by the number of fixations landing on any object (see Scialfa et al., in press).

With the exception of accuracy, analyses to follow were conducted only on correct responses. Any trial in which 5 sec. elapsed before a response was made was omitted. The data from one older participant were omitted from training session 1, and another participant's data were omitted from training session 12 and 13 as a result of recording error. Furthermore, one younger participant consistently made few or no eye movements throughout the training and as a result, no data regarding average fixation duration or the selection factor could be calculated. Thus this participant's data were also omitted for these variables.

All dependent measures were submitted to separate 2 (Age) X 2 (Presence) X 3 (Display Size) univariate split-plot Analyses of Variance (ANOVA), with age as a between-subjects factor and target-presence and display size as within-subjects factors. A Geisser-Greenhouse correction was used to correct for violations of sphericity, however, the reported data shows the degrees of freedom associated with the unprotected test. Planned comparisons were analyzed using a Bonferonni adjustment (Maxwell & Delaney, 1990).

To examine the data using a generalized slowing approach, after each training period, linear regressions were used to estimate fit. The slowing factor for RT and fixation number are presented in Brinley plots as a function of target-presence. Regressions for average fixation duration were not performed because older adults generally make more fixations, which reduces their average fixation duration (Scialfa &

Joffe, 1998). As well, first fixation duration, which is a indicator of display encoding, is not hypothesized to be influenced by the slowing factor and was also not analyzed.

Figure 2 shows the performance on each dependent measure over the 16 sessions as a function of age and target-presence. The figures provides a global picture of some general patterns in the data. First, improvement in search efficiency is evident in both younger and older adults. This is most clearly seen in the RT (Figure 2b) and fixation number data (Figure 2c). However the other variables are relatively stable throughout practice. Secondly, older adults generally perform less efficiently than younger adults. They had longer RTs (Figure 2b), more fixations (Figure 2c), and required longer first fixations (Figure 2d), and average fixations (Figure 2e). Thirdly, the selection factor data (Figure 2f) remained relatively constant and high for both age groups. Finally, upon the first reversal, there is disruption in RT and fixation number, whereas the other variables were less disrupted. Subsequent reversals did not produce much disruption, providing evidence for positive transfer.

First Session (Session 1) – Training Period 1.

Accuracy – As indicated in Table 3, target-present trials produced more errors, that is, missed signals, than target-absent trials (Figure 3a). No other effects were significant.

RTs – Figure 3c displays the RT as a function of age, presence, and display size. As indicated in Table 4a, older adults were slower at responding than younger adults; RTs were also slower on target-absent trials and increased with display size. The three-way interaction was also significant.

Table 3.

Analysis of Variance for Accuracy Session 1.

Source	df	F	p
Age	1, 17	.77	.393
Display Size	2, 34	1.78	.193
Presence	1, 17	22.50	<.001
Age X Display Size	2, 34	1.77	.194
Age X Presence	1, 17	1.83	.194
Display Size X Presence	2, 34	2.02	.156
Age X Display Size X Presence	2, 34	.89	.405

Table 4a.

Analysis of Variance for RT Session 1.

Source	df	F	p
Age	1, 17	13.50	.002
Display Size	2, 34	49.15	< .001
Presence	1, 17	44.27	< .001
Age X Display Size	2, 34	2.59	.12
Age X Presence	1, 17	13.83	.002
Display Size X Presence	2, 34	23.90	<.001
Age X Display Size X Presence	2, 34	4.14	.046

Table 4b.

Analysis of Variance for RT on Target Present Trials in Session 1.

Source	df	F	p
Age	1, 17	7.64	.013
Display Size	2, 34	23.55	<.001
Age X Display Size	2, 34	.35	.621

Table 4c.

Analysis of Variance for RT on Target Absent Trials in Session 1.

Source	df	F	p
Age	1, 17	17.25	.001
Display Size	2, 34	52.30	<.001
Age X Display Size	2, 34	4.11	.025

Post-hoc tests indicate that on target-present trials, both age groups performed comparably (Table 4b). Display size slopes for younger adults (15.82 ms/item) were similar to those of older adults (19.39 ms/item). However, on target-absent trials (Table 4c), display size slopes were much greater for older adults (49.35 ms/item) than younger adults (27.99 ms/item).

Fixation Number – Figure 3e shows the fixation number data for Session 1. As indicated in Table 5, no significant age difference was found, however more fixations were required as display size increased and on target-absent trials. Older adults made more fixations on target-absent trials, and more fixations were required as display size increased for target-absent trials, compared to target-present trials. No other effects were significant, however, the three-way interaction was marginal and in the same direction as RT. On target-present trials, for both younger (.05 fixations/item) and older adults (.03 fixations/item) showed relatively flat slopes, whereas on target-absent trials, both showed steeper slopes (Young = .12 fixations/item; Old = .17 fixations/item).

First Fixation Duration - Means for first fixation duration are plotted in Figure 4a. Older adults made longer first fixations, and first fixation durations increased as display size increased (Table 6). No other effects were significant.

Average Fixation Duration - As shown in Figure 4c, a significant age effect was found, with older adults having longer fixations (Table 7a). Longer fixations were also made on target-present trials, and generally tended to be longer at smaller display sizes. This finding is explained by Scialfa and Joffe's (1997) observation that average fixation duration decreases with more eye movements. Because larger display sizes require more

Table 5.

Analysis of Variance for Fixation Number Session 1.

Source	df	F	p
Age	1, 17	3.20	.092
Display Size	2, 34	91.54	< .001
Presence	1, 17	108.45	< .001
Age X Display Size	2, 34	.39	.599
Age X Presence	1, 17	7.69	.013
Display Size X Presence	2, 34	20.45	<.001
Age X Display Size X Presence	2, 34	2.77	.094

Table 6.

Analysis of Variance for First Fixation Duration Session 1.

Source	df	F	p
Age	1, 17	5.46	.032
Display Size	2, 34	17.73	< .001
Presence	1, 17	1.91	.185
Age X Display Size	2, 34	.69	.474
Age X Presence	1, 17	.38	.546
Display Size X Presence	2, 34	1.36	.27
Age X Display Size X Presence	2, 34	1.30	.285

Table 7a.

Analysis of Variance for Average Fixation Duration Session 1.

Source	df	F	p
Age	1, 17	6.64	.02
Display Size	2, 34	6.42	.005
Presence	1, 17	53.58	<.001
Age X Display Size	2, 34	2.06	.144
Age X Presence	1, 17	.25	.622
Display Size X Presence	2, 34	1.39	.262
Age X Display Size X Presence	2, 34	3.50	.042

Table 7b.

Analysis of Variance for Average Fixation Duration on Target Present Trials in Session 1.

Source	df	F	p
Age	1, 17	4.82	.042
Display Size	2, 34	5.32	.01
Age X Display Size	2, 34	4.40	.021

Table 7c.

Analysis of Variance for Average Fixation Duration on Target Absent Trials in Session 1.

Source	df	F	p
Age	1, 17	9.52	.007
Display Size	2, 34	2.31	.125
Age X Display Size	2, 34	.05	.928

fixations to find the target. average fixation duration decreases with display size. The three-way interaction was also significant.

On target-present trials (Table 7b), compared to older adults, younger adults show a steeper reduction on average fixation duration with display size, suggesting that at a small display size, younger adults are doing more processing on each individual fixation. On target-absent trials (Table 7c), there is no Age X Display Size interaction, suggesting both groups are using more similar search strategies.

Selection Factor - The selection factor as a function of age, display size, and presence is shown in Figure 4e. The selection factor for both age groups was quite high. Only when display size was 24 items and the target was absent, did the selection factor drop to .70 for both age groups. On average, the selection factor declined on target-absent trials and as display size increased, but no age differences were found (Table 8).

Last Session (Session 4) – Training Period 1.

Accuracy – Shown in Figure 3b, more errors were made on target-present trials than target-absent trials (Table 9). As well, there was a marginal effect of display size with more errors occurring on larger display sizes. The Display Size X Target-Presence interaction was also significant, suggesting that more errors occurred on target-present trials relative target-absent trials as a function of display size. Again, these are missed signals, a common finding in search.

RTs - Figure 3d shows the RT data for Session 4 as a function of age, display size and presence. Compared to Session 1, RT has declined for both age groups, demonstrating improvement in search efficiency with training. Display size slopes on target-present trials are near zero for both younger adults (5.31 ms/item) and older adults

Table 8.

Analysis of Variance for Selection Factor Session 1.

Source	df	F	p
Age	1, 17	.59	.452
Display Size	2, 34	18.60	<.001
Presence	1, 17	40.04	< .001
Age X Display Size	2, 34	.99	.384
Age X Presence	1, 17	3.50	.079
Display Size X Presence	2, 34	1.82	.183
Age X Display Size X Presence	2, 34	1.36	.269

Table 9.

Analysis of Variance for Accuracy Session 4.

Source	df	F	p
Age	1, 18	0.59	.452
Display Size	2, 36	2.90	.076
Presence	1, 18	10.05	.005
Age X Display Size	2, 36	.17	.820
Age X Presence	1, 18	.08	.776
Display Size X Presence	2, 36	3.75	.042
Age X Display Size X Presence	2, 36	.05	.926

(4.84 ms/item) suggesting automatic processing. Despite improvements in overall RT, age, display size and presence effects were still significant as indicated in Table 10a. As well, the three-way interaction was also significant, with older adults still having a greater a display size effect in the target-absent condition. Post hoc analysis confirmed that although both age groups performed equivalently as a function of display size on target-present trials (Table 10b), on target-absent trials (Table 10c), older adults were significantly slower. Still, display size slopes on target-absent trials for both groups (Young = 13.88 ms/item; Old = 29.09 ms/item) were approximately one-half of that in Session 1.

Fixation Number - The age difference in fixation number became more apparent after training. Recall that there were only marginal effects of age in Session 1 for fixation number. As shown Figure 3f, older adults made more fixations, and the more fixations were made on target-absent trials and with increasing display sizes (Table 11a). The three-way interaction was also significant. Post hoc analysis shows a similar pattern to the RT data. On target-present trials (Table 11b), no display size effects were found for either age group. Display size slopes were .02 fixations/item and .01 fixations/item for younger and older adults, respectively. In contrast, on target-absent trials (Table 11c), older adults required more fixations (.12 fixations/item) as display size increased relative to younger adults (.05 fixations/item), suggesting that older adults were performing more overt search.

First Fixation Duration - Figure 4b shows the mean first fixation duration as a function of age, display size and presence. There was a main effect of age and first fixations were longer with increasing display size (Table 12). Older adults also had

Table 10a.

Analysis of Variance for RT Session 4.

Source	df	F	p
Age	1, 18	22.13	<.001
Display Size	2, 36	34.56	< .001
Presence	1, 18	55.04	< .001
Age X Display Size	2, 36	2.66	.103
Age X Presence	1, 18	16.48	.001
Display Size X Presence	2, 36	49.64	<.001
Age X Display Size X Presence	2, 36	11.25	.001

Table 10b.

Analysis of Variance for RT on Target Present Trials in Session 4.

Source	df	F	p
Age	1, 18	14.54	.001
Display Size	2, 36	4.58	.03
Age X Display Size	2, 36	.01	.967

Table 10c.

Analysis of Variance for RT on Target Absent Trials in Session 4.

Source	df	F	p
Age	1, 18	26.46	< .001
Display Size	2, 36	63.02	<.001
Age X Display Size	2, 36	7.88	.004

Tablel la.

Analysis of Variance for Fixation Number Session 4.

Source	df	F	p
Age	1, 18	13.77	.002
Display Size	2, 36	27.57	<.001
Presence	1, 18	89.47	< .001
Age X Display Size	2, 36	2.87	.085
Age X Presence	1, 18	21.64	<.001
Display Size X Presence	2, 36	18.77	<.001
Age X Display Size X Presence	2, 36	5.47	.013

Table 11b.

Analysis of Variance for Fixation Number for Target-Present in Session 4.

Source	df	F	p
Age	1, 18	6.64	.019
Display Size	2, 36	2.51	.121
Age X Display Size	2, 36	.15	.758

Table 11c.

Analysis of Variance for Fixation Number for Target-Absent in Session 4.

Source	df	F	p
Age	1, 18	18.33	< .001
Display Size	2, 36	36.30	< .001
Age X Display Size	2, 36	6.33	.005

Table 12.

Analysis of Variance for First Fixation Duration Session 4.

Source	df	F	p
Age	1, 18	5.77	.027
Display Size	2, 36	33.11	< .001
Presence	1, 18	2.49	.132
Age X Display Size	2, 36	4.74	.026
Age X Presence	1, 18	2.86	.108
Display Size X Presence	2, 36	1.22	.305
Age X Display Size X Presence	2, 36	2.55	.098

longer first fixations with display size, suggesting older adults required more time to process the display and to program an initial saccade when more items were present. No other effect was significant.

Average Fixation Duration - As shown in Figure 4d, older adults had longer average fixation durations (Table 13). Fixation durations also were longer on target-present trials, and declined as display size increased. No other effects were significant.

Selection Factor - Shown in Figure 4f, the selection factor still clearly favours white objects, and has not changed from Session 1. As shown in Table 14, no age differences were evident, however the selection factor continued to decline on target-absent trials and with increasing display size. The selection factor also decreased more for older adults as a display size increased.

Generalized Slowing - Training Period 1.

Brinley plots showing RT and fixation number as a function of target-presence are presented in two separate plots in Figure 5 along with the linear functions of the regression line, and the r^2. Examining the RT data from Figure 5a, the r^2 is considerably lower than what is expected by the generalized slowing hypothesis. As well, with the exception of the slope on target- absent trials, parameter estimates do not strongly support generalized slowing, which commonly reports slopes approximating 1.5 and negative intercepts.

The fixation number data (Figure 5b) reflects a very similar pattern to the RT data, however the strong relationship found by Scialfa and Joffe (1998) was not found here. Still, the data suggest a moderate linear relationship between aging and fixation number that is not predicted by generalized slowing. Interestingly, for both RT and

Table 13.

Analysis of Variance for Average Fixation Duration Session 4.

Source	df	F	p
Age	1, 18	8.75	.008
Display Size	2, 36	6.84	.003
Presence	1, 18	34.89	<.001
Age X Display Size	2, 36	1.09	.34
Age X Presence	1, 18	1.14	.299
Display Size X Presence	2, 36	.39	.646
Age X Display Size X Presence	2, 36	.42	.628

Table 14.

Analysis of Variance for Selection Factor Session 4.

Source	df	F	p
Age	1, 17	.06	.814
Display Size	2, 34	64.96	<.001
Presence	1, 17	35.66	< .001
Age X Display Size	2, 34	4.36	.025
Age X Presence	1, 17	.28	.601
Display Size X Presence	2, 34	1.94	.165
Age X Display Size X Presence	2, 34	1.06	.35

fixation number, target-absent slopes are greater than target-present slopes, suggesting that older adults are having more difficulty on target-absent trials. This parallels the RT and fixation number data found in the ANOVAs.

Reversal 1.

To calculate the amount of disruption, the difference scores of Session 5 and Session 4 for each condition was computed. This difference score was then divided by the baseline score (Session 4) and multiplied by 100 to arrive at the percent of disruption. Thus, positive values suggest performance suffered after reversal.

Errors were again relatively low, and thus disruption scores could not be calculated for the majority of participants because it resulted in divisions by zero (i.e. when no errors were made for a given condition). Therefore, accuracy analyses will not be reported for any of the reversal conditions.

RTs - Figure 6a shows the percent disruption as a function of age, display size and presence. Overall, participants were disrupted by the reversal condition. However, as shown in Table 15, the main effect of age was not significant, although disruption scores for RT increased with display size and on target-present trials. The Age X Presence interaction was marginally significant ($p = .081$), suggesting that younger adults were more disrupted on target-present trials than on target-absent trials compared to older adults. No other effects were significant.

Fixation Number - As shown in Figure 6b, fixation number also increased upon reversal. Again, no significant main effect of age was found but fixation number increased with display size and on target-present trials (Table 16). The Age X Target-

Table 15.

Analysis of Variance for RT Reversal 1.

Source	df	F	p
Age	1, 18	.43	.518
Display Size	2, 36	6.40	.013
Presence	1, 18	9.21	.007
Age X Display Size	2, 36	.12	.796
Age X Presence	1, 18	3.41	.081
Display Size X Presence	2, 36	.59	.521
Age X Display Size X Presence	2, 36	1.30	.281

Table 16.

Analysis of Variance for Fixation Number Reversal 1.

Source	df	F	p
Age	1, 18	.00	.98
Display Size	2, 36	2.86	.102
Presence	1, 18	21.44	<.001
Age X Display Size	2, 36	.12	.764
Age X Presence	1, 18	4.86	.041
Display Size X Presence	2, 36	1.51	.237
Age X Display Size X Presence	2, 36	.51	.53

Presence interaction was also significant, suggesting that younger adults were more disrupted on target-present trials. No other effects were significant.

First Fixation Duration - The disruption scores for first fixation data is shown in Figure 6c. No age differences were found, although there was a marginal effect of target-presence with target-absent trials producing more disruption (Table 17). No other effects were significant.

Average Fixation Duration - Figure 6d shows the disruption scores for average fixation duration. As shown in Table 18, no effects were significant.

Selection Factor - Figure 6e shows the disruption scores for the selection factor. No age differences were found, however there was more disruption was found on target-absent trials (Table 19). Moreover there was a significant display size effect however, this effect did not seem to follow any observable pattern. Similarly, the Presence X Display Size interaction was significant, but again, the pattern is not systematic.

<u>First Session (Session 5) - Training Period 2.</u>

Accuracy – As shown in Table 20, again more errors were made on target-present trials, and errors increased as a function of display size. A Display Size X Target-Presence interaction was also found, suggesting an increase in errors on target-present trials when the display size was 24 items (Figure 7a).

RT – As shown in Figure 7c and confirmed in Table 21, older adults required more time to perform the task. RT also increased as display size increased and on target-absent trials. Older adults performed more slowly on target-absent trials and as display size increased, relative to younger adults. Performance for both age groups was slower

Table 17.

Analysis of Variance for First Fixation Duration Reversal 1.

Source	df	F	p
Age	1, 18	0.0	.990
Display Size	2, 36	1.98	.169
Presence	1, 18	3.71	.07
Age X Display Size	2, 36	1.50	.24
Age X Presence	1, 18	1.62	.220
Display Size X Presence	2, 36	.87	.417
Age X Display Size X Presence	2, 36	.08	.901

Table 18.

Analysis of Variance for Average Fixation Duration Reversal 1.

Source	df	F	p
Age	1, 18	.49	.492
Display Size	2, 36	1.94	.161
Presence	1, 18	.59	.452
Age X Display Size	2, 36	.15	.851
Age X Presence	1, 18	2.03	.171
Display Size X Presence	2, 36	.90	.415
Age X Display Size X Presence	2, 36	.11	.894

Table 19.

Analysis of Variance for Selection Factor for Reversal 1.

Source	df	F	p
Age	1, 18	.01	.931
Display Size	2, 36	5.72	.008
Presence	1, 18	7.75	.012
Age X Display Size	2, 36	2.11	.138
Age X Presence	1, 18	.00	.955
Display Size X Presence	2, 36	4.35	.028
Age X Display Size X Presence	2, 36	.33	.679

Table 20.

Analysis of Variance for Accuracy Session 5.

Source	df	F	p
Age	1, 18	.82	.377
Display Size	2, 36	32.58	<.001
Presence	1, 18	36.60	<.001
Age X Display Size	2, 36	.90	.38
Age X Presence	1, 18	.43	.523
Display Size X Presence	2, 36	30.13	<.001
Age X Display Size X Presence	2, 36	.55	.580

Table 21.

Analysis of Variance for RT Session 5.

Source	df	F	p
Age	1, 17	31.67	<.001
Display Size	2, 34	65.23	< .001
Presence	1, 17	36.53	< .001
Age X Display Size	2, 34	3.05	.085
Age X Presence	1, 17	8.65	.009
Display Size X Presence	2, 34	22.81	<.001
Age X Display Size X Presence	2, 34	1.95	.175

on target-absent trials as display size increased. The three-way interaction was not significant.

As a result of reversal, display size slopes for both groups increased to levels indicative of controlled processing. The target-present to target-absent slope ratio for both age groups approximated 2:1. On target-present trials, the display size slopes were 11.47 ms/item and 15.83 ms/item for younger adults and older adults, respectively. On target-absent trials, the display size slopes were 23.80 ms/item and 38.77 ms/item for younger adults and older adults, respectively.

Fixation Number – Fixation number increased as a result of reversal as shown in Figure 7e. Older adults still made more fixations than younger adults (Table 22). Fixations increased as display size increased and on target-absent trials. Compared to younger adults, older adults required more fixations on target-absent trials (Young = .10 fixations/items; Old = .17 fixations/item) than on target-present trials (Young = .05 fixations/items; Old = .05 fixations/item) and for both groups, there were significantly more fixations made on target-absent trials as display size increased. No other effects were significant.

First Fixation Duration – As shown in Figure 8a, older adults had longer first fixations, and first fixations increased with display size (Table 23). First fixations also increased with display size, and this effect was more pronounced for older adults. No other effects were significant.

Average Fixation Duration – Average fixation durations are shown in Figure 8c. Older adults had longer average fixations durations and fixations were also longer on

Table 22.

Analysis of Variance for Fixation Number Session 5.

Source	df	F	p
Age	1, 18	9.88	.006
Display Size	2, 36	39.99	< .001
Presence	1, 18	75.31	< .001
Age X Display Size	2, 36	1.05	.334
Age X Presence	1, 18	17.71	.001
Display Size X Presence	2, 36	14.83	<.001
Age X Display Size X Presence	2, 36	1.49	.24

Table 23.

Analysis of Variance for First Fixation Duration Session 5.

Source	df	F	p
Age	1, 18	8.18	.01
Display Size	2, 36	23.15	< .001
Presence	1, 18	.44	.516
Age X Display Size	2, 36	7.02	.008
Age X Presence	1, 18	.52	.481
Display Size X Presence	2, 36	.12	.841
Age X Display Size X Presence	2, 36	.96	.378

Table 24.

Analysis of Variance for Average Fixation Duration Session 5.

Source	df	F	p
Age	1, 18	9.83	.006
Display Size	2, 36	4.77	.02
Presence	1, 18	12.95	.002
Age X Display Size	2, 36	1.00	.368
Age X Presence	1, 18	2.83	.110
Display Size X Presence	2, 36	.99	.375
Age X Display Size X Presence	2, 36	.52	.586

target-present trials (Table 24). The main effect of display size was significant, however there is no clear observable pattern for this effect.

Selection Factor – Because of the reversal, the selection factor now represents the number of fixations landing on a black object, divided by the number of fixations landing on any object. As shown in Figure 8e, the selection factor remained relatively stable despite reversal. Again, there were no age differences in the selection factor, however the selection factors declined with display size and on target-absent trials (Table 25). The Display Size X Target-Presence interaction was also significant suggesting that the decline of the selection factor was greater for target-present trials than target-absent trials.

Last Session (Session 8) -Training Period 2.

Accuracy – Target-present trials again produced more errors than target-absent trials (Table 26) and again, this interacted with display size. Examining Figure 7b, once again, at the largest display size more errors are made on target-present trial than target-absent trials.

RT – Similar to Session 5, all effects were significant with the exception of the three-way interaction (Table 27). Shown in Figure 7d, RTs for older adults were greater than younger adults. RTs were also longer as display size increased and on target-absent trials. Older adults required more time to respond as display size increased and on target-absent trials relative to younger adults. Moreover, for both age groups, target-absent trials required more time as display size increased.

Once again, practice effects were observed for both age groups. On target-present trials, both age groups had display size slopes indicative of automatic processing (Young

Table 25.

Analysis of Variance for Selection Factor Session 5.

Source	df	F	p
Age	1, 18	.10	.751
Display Size	2, 36	18.43	<.001
Presence	1, 18	11.21	.004
Age X Display Size	2, 36	.72	.464
Age X Presence	1, 18	.36	.554
Display Size X Presence	2, 36	3.54	.049
Age X Display Size X Presence	2, 36	.03	.949

Table 26.

Analysis of Variance for Accuracy Session 5.

Source	df	F	p
Age	1, 18	.82	.377
Display Size	2, 36	32.58	<.001
Presence	1, 18	36.60	<.001
Age X Display Size	2, 36	.90	.38
Age X Presence	1, 18	.43	.523
Display Size X Presence	2, 36	30.13	<.001
Age X Display Size X Presence	2, 36	.55	.580

Table 27.

Analysis of Variance for RT Session 5.

Source	df	F	p
Age	1, 17	31.67	<.001
Display Size	2, 34	65.23	< .001
Presence	1, 17	36.53	< .001
Age X Display Size	2, 34	3.05	.085
Age X Presence	1, 17	8.65	.009
Display Size X Presence	2, 34	22.81	<.001
Age X Display Size X Presence	2, 34	1.95	.175

= 4.94 ms/item: Old = 8.65 ms/item), whereas, on target-absent trials, slopes continued to indicate greater difficulty for the elderly (Young = 15.42 ms/item: Old = 28.10 ms/item).

Fixation Number – Fixation number decreased relative to Session 5 suggesting improvement in search efficiency (Figure 7f). Shown in Table 28, more fixations were made by older adults: fixations increased on target-absent trials and as display size increased. Moreover, older adults made more fixations as display size increased and on target-absent trials compared to younger adults. For both age groups, on target-absent trials more fixations were made as display size increased. The three-way interaction was marginally significant ($p = .085$). However, display size slopes showed relatively comparable slopes. On target-present trials, display size slopes were .03 fixations/item for younger adults and .02 fixations/item for older adults and for target-absent trials, slopes were .08 fixations/item for younger adults and .07 fixations/item for older adults.

First Fixation Duration – Shown in Figure 8b, the main effect of age was marginally significant, suggesting that older adults had slightly longer first fixations (Table 29). Longer first fixations were also required as display size increased. No other effects were significant.

Average Fixation Duration – As shown in Figure 8d, average fixation durations are shorter relative to Session 5. Average fixation durations were still longer for older adults, and on target-present trials (Table 30). There was also a main effect of display size, with longer fixations at Display Size 6 relative to Display Size 12 and 24. Older adults also had longer average fixations on target-present trials compared to target-absent

Table 28.

Analysis of Variance for Fixation Number Session 8.

Source	df	F	p
Age	1, 17	11.70	.003
Display Size	2, 34	37.79	< .001
Presence	1, 18	71.74	< .001
Age X Display Size	2, 36	2.49	.113
Age X Presence	1, 18	9.42	.007
Display Size X Presence	2, 36	28.02	<.001
Age X Display Size X Presence	2, 36	2.84	.085

Table 29.

Analysis of Variance for First Fixation Duration Session 5.

Source	df	F	p
Age	1, 18	8.18	.01
Display Size	2, 36	23.15	< .001
Presence	1, 18	.44	.516
Age X Display Size	2, 36	7.02	.008
Age X Presence	1, 18	.52	.481
Display Size X Presence	2, 36	.12	.841
Age X Display Size X Presence	2, 36	.96	.378

Table 30.

Analysis of Variance for Average Fixation Duration Session 5.

Source	df	F	p
Age	1, 18	9.83	.006
Display Size	2, 36	4.77	.02
Presence	1, 18	12.95	.002
Age X Display Size	2, 36	1.00	.368
Age X Presence	1, 18	2.83	.110
Display Size X Presence	2, 36	.99	.375
Age X Display Size X Presence	2, 36	.52	.586

trials, whereas younger adults had comparable average fixation durations as a function of target-presence.

Selection Factor – The selection factor again remains high throughout the second training period (Figure 8f). Shown in Table 31, no age differences were found, however again, the selection factor declined as display size increased and on target-absent trials. There was also a marginal effect of Display Size X Target-Presence ($p = .068$), suggesting that the selection factor was higher on target-present trials and at smaller display sizes. No other effects were significant.

Generalized Slowing - Training Period 2.

Compared to Training Period 1, the RT data in Training Period 2 provides more support for the generalized slowing account (Figure 9a). The r^2 and function parameters are more suggestive of generalized slowing. However, the fixation number for older adults also is strongly related to younger adult fixations (Figure 9b), suggesting a slowing in oculomotor involvement as well as in processing time.

Again, slopes in both RT and fixation number increase on target-absent trials, suggesting that target-absent trials are more problematic for older adults. This result parallels the information provided by the RT and fixation number data in the ANOVAs.

Reversal 2.

RT – Shown in Figure 10a, the data for the second reversal is markedly different from the first reversal. Little disruption is evident. In fact, for the most part, RT improved from Session 8 to Session 9. Shown in Table 32, age differences were significant, with older adults showing greater improvement than younger adults (who showed either no improvement or some disruption). However, this may suggest floor

Table 31.

Analysis of Variance for Selection Factor Session 8.

Source	df	F	p
Age	1, 17	.08	.783
Display Size	2, 34	43.09	<.001
Presence	1, 17	7.62	.013
Age X Display Size	2, 34	.72	.464
Age X Presence	1, 17	1.17	.294
Display Size X Presence	2, 34	2.95	.068
Age X Display Size X Presence	2, 34	1.52	.234

Table 32.

Analysis of Variance for RT Reversal 2.

Source	df	F	p
Age	1, 18	8.49	.009
Display Size	2, 36	9.73	.001
Presence	1, 18	.01	.909
Age X Display Size	2, 36	3.26	.054
Age X Presence	1, 18	1.92	.182
Display Size X Presence	2, 36	.36	.687
Age X Display Size X Presence	2, 36	2.41	.109

effects for younger adults. such that little improvement can been seen. The main effect of display size was also significant however the data are difficult to interpret. RT at Display Size 12 indicates greater improvement than on Display Size 6 or 24. No other effects were significant.

Fixation Number – Shown in Figure 10b. both the main effects of age and display size were marginally significant and the Age X Display size interaction was significant (Table 33). Fixation number for younger adults generally remained stable across display size at reversal. however for older adults. fixation number generally improved. particularly for Display Size 12.

First Fixation Duration – As shown in Figure 10c, first fixation durations also showed little or no disruption and no effects were significant (Table 34).

Average Fixation Duration – Similar to first fixation duration, Figure 10d shows the reversal data for average fixation duration (Table 35). Little or no disruption was evident and no effects were significant.

Selection Factor – Shown in Figure 10e, no main effect of age was found on the selection factor, however. more disruption (or less benefit) was evident on Display Size 12 and 24. and there was less benefit on target-present trials (Table 36). The Age X Display Size interaction was also significant. with younger adults showing less benefit on higher display sizes. whereas older adults showed less benefit only on Display Size 12.

First Training Session (Session 9) – Training Period 3.

Accuracy – Show in Figure 11a, younger adults committed more errors than older adults and more errors were committed on target-present trials (Table 37). The Age X

Table 33.

Analysis of Variance for Fixation Number Reversal 2.

Source	df	F	p
Age	1, 17	3.29	.087
Display Size	2, 34	3.29	.068
Presence	1, 17	.08	.783
Age X Display Size	2, 34	4.43	.033
Age X Presence	1, 17	3.62	.074
Display Size X Presence	2, 34	1.06	.352
Age X Display Size X Presence	2, 34	.57	.549

Table 34.

Analysis of Variance for First Fixation Duration Reversal 2.

Source	df	F	p
Age	1, 18	.01	.919
Display Size	2, 36	.51	.561
Presence	1, 18	.02	.885
Age X Display Size	2, 36	1.71	.202
Age X Presence	1, 18	.48	.496
Display Size X Presence	2, 36	.61	.524
Age X Display Size X Presence	2, 36	1.45	.249

Table 35.

Analysis of Variance for Average Fixation Duration Reversal 2.

Source	df	F	p
Age	1, 18	2.40	.139
Display Size	2, 36	.98	.384
Presence	1, 18	.20	.660
Age X Display Size	2, 36	1.28	.292
Age X Presence	1, 18	2.58	.127
Display Size X Presence	2, 36	2.13	.142
Age X Display Size X Presence	2, 36	1.12	.333

Table 36.

Analysis of Variance for Selection Factor Reversal 2.

Source	df	F	p
Age	1, 17	.96	.341
Display Size	2, 34	11.24	<.001
Presence	1, 17	5.52	.031
Age X Display Size	2, 34	4.68	.019
Age X Presence	1, 17	.76	.396
Display Size X Presence	2, 34	4.54	.02
Age X Display Size X Presence	2, 34	1.91	.167

Table 37.

<u>Analysis of Variance for Accuracy Session 9.</u>

Source	df	F	p
Age	1, 18	8.62	.009
Display Size	2, 36	.93	.397
Presence	1, 18	24.74	< .001
Age X Display Size	2, 36	.70	.491
Age X Presence	1, 18	4.76	.043
Display Size X Presence	2, 36	3.49	.058
Age X Display Size X Presence	2, 36	1.72	.202

Presence interaction was also significant, with older adults having more errors particularly on Display Size 24 on target-present trials, whereas younger adults had more errors on target-present trials in general. There was also a marginal Display Size X Target-Presence interaction, with errors increasing as a function of display size on target-present trials, but no display size effect on target-absent trials.

RT – The RT data for Session 9 is shown in Figure 11c. Older adults were slower than younger adults, target-absent trials were slower than target-present trials, and RT increased with display size (Table 38a). Older adults were also slower on target-absent trials and were slower at greater display sizes. Target-absent trials also were significantly slower than target-present trials as display size increased for both age groups. The three-way interaction was also significant.

Post hoc tests revealed that, similar to Training Session 1, on target-present trials, both age groups performed comparably (Table 38b), whereas older adults had more difficulty on target-absent trials as display size increased (Table 38c). However, note that display size slopes have not increased as a result of reversal for either age group. For target-present trials, display size slopes are still indicative of automatic processing, (Young = 6.04 ms/item; Old = 7.75 ms/item), and for target-absent trials, both age groups continue to exhibit controlled processing (Young = 15.26 ms/item; Old = 33.02 ms/item).

Fixation Number – Shown in Figure 11e, the fixation number data reflect a similar pattern found in RT at Session 9. Older adults required more fixations to perform the task than younger adults; fixation number increased on target-absent trials relative to target-present trials and as display size increased (Table 39a). Older adults required more fixations on target-absent trials and on increasing display sizes. Target-absent trials also

Table 38a.

Analysis of Variance for RT Session 9.

Source	df	F	p
Age	1, 18	32.35	< .001
Display Size	2, 36	75.76	< .001
Presence	1, 18	54.42	< .001
Age X Display Size	2, 36	8.36	.004
Age X Presence	1, 18	12.17	.003
Display Size X Presence	2, 36	55.11	< .001
Age X Display Size X Presence	2, 36	11.66	.002

Table 38b.

<u>Analysis of Variance for RT on Target Present Trials in Session 9.</u>

Source	df	F	p
Age	1, 18	21.88	<.001
Display Size	2, 36	24.97	<.001
Age X Display Size	2, 36	1.97	.167

Table 38c.

<u>Analysis of Variance for RT on Target Absent Trials in Session 9.</u>

Source	df	F	p
Age	1, 18	36.63	< .001
Display Size	2, 36	82.62	< .001
Age X Display Size	2, 36	11.44	.002

Table 39a.

Analysis of Variance for Fixation Number Session 9.

Source	df	F	p
Age	1, 17	10.29	.005
Display Size	2, 34	97.97	< .001
Presence	1, 17	87.40	< .001
Age X Display Size	2, 34	9.07	.001
Age X Presence	1, 17	20.35	< .001
Display Size X Presence	2, 34	32.35	< .001
Age X Display Size X Presence	2, 34	9.11	.005

Table 39b.

Analysis of Variance for Fixation Number on Target Present Trials in Session 9.

Source	df	F	p
Age	1, 18	3.97	.062
Display Size	2, 36	16.37	<.001
Age X Display Size	2, 36	2.65	.094

Table 39c.

Analysis of Variance for Fixation Number on Target Absent Trials in Session 9.

Source	df	F	p
Age	1, 17	16.85	.001
Display Size	2, 34	90.22	< .001
Age X Display Size	2, 34	12.26	.001

required more fixations in general than target-present trials as display size increased. The three-way interaction was also significant.

Post hoc tests again revealed that whereas on target-present trials (Table 39b), both age groups performed comparably (Young = .03 fixations/item; Old = .02 fixations/item), older adults had more difficulty on target-absent trials (Table 39c) as display size increased (.13 fixations/item) than younger adults (.07 fixations/item).

First Fixation Duration – Shown in Figure 12a, first fixation durations continued to be longer for older adults (Table 40). As well, first fixations also were longer as display size increased. No other effects were significant.

Average Fixation Duration – Shown in Figure 12c, average fixation durations were longer for older adults and for target-present trials (Table 41). Average fixations were also longer for Display Size 6 and then stabilized for Display Size 12 and 24. No other effects were significant.

Selection Factor –Similar to previous sessions, the selection factor remained quite high for both age groups (Figure 12e). Table 42 indicates no age differences were significant. The selection factor again was higher on target-present trials, and declined as display size increased.

Last Training Session (Session 12) – Training Period 3.

Accuracy – As presented in Figure 11b, younger adults committed more errors than older adults (Table 43), and again, more errors were made on target-present trials. No other effects were significant.

RT – A reduction of RT is evident over Training Period 3 as shown in Figure 11d and 9f. For Session 12, once again, all effects were significant. Shown in Table 44a,

Table 40.

Analysis of Variance for First Fixation Duration Session 9.

Source	df	F	p
Age	1, 18	4.41	.05
Display Size	2, 36	7.48	.005
Presence	1, 18	.86	.365
Age X Display Size	2, 36	2.44	.119
Age X Presence	1, 18	.62	.441
Display Size X Presence	2, 36	1.27	.283
Age X Display Size X Presence	2, 36	1.12	.315

Table 41.

Analysis of Variance for Average Fixation Duration Session 9.

Source	df	F	p
Age	1, 17	9.60	.007
Display Size	2, 34	7.25	.007
Presence	1, 17	17.34	.001
Age X Display Size	2, 34	.54	.533
Age X Presence	1, 17	.18	.677
Display Size X Presence	2, 34	.97	.374
Age X Display Size X Presence	2, 34	.56	.541

Table 42.

Analysis of Variance for Selection Factor Session 9.

Source	df	F	p
Age	1, 17	.44	.518
Display Size	2, 34	43.91	< .001
Presence	1, 17	28.48	< .001
Age X Display Size	2, 34	3.13	.062
Age X Presence	1, 17	.10	.755
Display Size X Presence	2, 34	5.27	.011
Age X Display Size X Presence	2, 34	1.86	.171

Table 43.

Analysis of Variance for Accuracy Session 12.

Source	df	F	p
Age	1, 17	8.78	.009
Display Size	2, 34	1.85	.197
Presence	1, 17	11.44	.004
Age X Display Size	2, 34	.39	.653
Age X Presence	1, 17	.82	.377
Display Size X Presence	2, 34	.73	.49
Age X Display Size X Presence	2, 34	.18	.833

relative to younger adults, older adults were needed more time to respond. Target-absent trials were slower than target-present trials, and RT increased with display size. Older adults were also slower on target-absent trials and were slower at greater display sizes. Target-absent trials also were significantly slower than target-present trials as display size increased. The three-way interaction was also significant.

Post hoc tests revealed that on both target-present (Table 44b) and target-absent (Table 44c) trials, younger adults performed more quickly than older adults with increases in display size. However, display size slopes still indicate for younger adults both target-present (2.03 ms/item) and target-absent (7.83 ms/item) slopes are near zero. However, for older adults, although the target-present slope suggests levels that are indicative of automatic processing (8.55 ms/item), the target-absent slope is still clearly indicating controlled processing (30.08 ms/item).

Fixation Number – As shown in Figure 11f, fixation number declined through the third training period. Older adults continued to make more fixations and more fixations were made on target-absent trials and as display size increased (Table 45). Older adults also required more fixations on target-absent trials and as display size increased (.09 fixations/item) relative to younger adults (.04 fixations/item). On target-present trials, the slopes were more comparable (Young = .01 fixations/item; Old = .03 fixations/item). In addition, fixation number increased on target-absent trials as display size increased relative to target-present trials. The three-way interaction was not significant.

First Fixation Duration – First fixation data is shown in Figure 12b. Older adults exhibited longer first fixations than younger adults and first fixations increased with an increase in display size (Table 46a). The three-way interaction was significant.

Table 44a.

Analysis of Variance for RT Session 12.

Source	df	F	p
Age	1, 17	67.13	< .001
Display Size	2, 34	59.62	< .001
Presence	1, 17	71.82	< .001
Age X Display Size	2, 34	21.29	< .001
Age X Presence	1, 17	15.94	.001
Display Size X Presence	2, 34	56.51	< .001
Age X Display Size X Presence	2, 34	18.39	< .001

Table 44b.

Analysis of Variance for RT on Target Present Trials in Session 12.

Source	df	F	p
Age	1, 17	61.11	<.001
Display Size	2, 34	30.89	<.001
Age X Display Size	2, 34	12.53	<.001

Table 44c.

Analysis of Variance for RT on Target Absent Trials in Session 12.

Source	df	F	p
Age	1, 17	58.81	< .001
Display Size	2, 34	63.24	< .001
Age X Display Size	2, 34	21.83	.002

Table 45.

Analysis of Variance for Fixation Number Session 12.

Source	df	F	p
Age	1, 16	12.74	.003
Display Size	2, 32	38.66	< .001
Presence	1, 16	63.18	< .001
Age X Display Size	2, 32	6.4	.005
Age X Presence	1, 16	17.10	.001
Display Size X Presence	2, 32	8.44	.003
Age X Display Size X Presence	2, 32	1.43	.256

Table 46a.

Analysis of Variance for First Fixation Duration Session 12.

Source	df	F	p
Age	1, 17	5.12	.037
Display Size	2, 34	36.02	< .001
Presence	1, 17	.95	.343
Age X Display Size	2, 34	1.77	.195
Age X Presence	1, 17	1.98	.177
Display Size X Presence	2, 34	2.74	.081
Age X Display Size X Presence	2, 34	5.66	.008

Table 46b.

Analysis of Variance for First Fixation Duration on Target Present Trials in Session 12.

Source	df	F	p
Age	1, 17	6.20	.023
Display Size	2, 34	25.26	<.001
Age X Display Size	2, 34	6.80	.01

Table 46c.

Analysis of Variance for First Fixation Duration on Target Absent Trials in Session 12.

Source	df	F	p
Age	1, 17	4.08	.06
Display Size	2, 34	24.33	< .001
Age X Display Size	2, 34	.13	.839

Post hoc analysis revealed a significant Age X Display Size interaction for target-present trials (Table 46b), but not for target-absent trials (Table 46c). Analysis of the display size slopes indicates comparable slopes in the target-absent condition for both age groups (Young = 2.18 ms/item; Old = 1.97 ms/item), but in the target-present condition, the slope for younger adults was considerably smaller (Young = .9 ms/item; Old = 2.86 ms/item).

Average Fixation Duration – In general, average fixation duration did not decrease in the third training session (Figure 12d). Older adults still had longer average fixations than younger adults as seen in Table 47a and longer fixations were made as display size increased. The three-way interaction was also significant.

Post hoc tests reveal that on target-present trials (Table 47b), older adults are slower, but perform comparably to younger adults. On target-absent trials (Table 47c), again older adults are slower, and there was a marginal effect of display size (p = .051).

Selection Factor – The selection factor data for Session 12 is presented in Figure 12f. No age differences were significant (Table 48). The selection factor decreased on target-absent trials and as display size increased. No other effects were significant.

Generalized Slowing - Training Period 3.

The Brinley plot for RT in Training Period 3 once again provides little support for generalized slowing (Figure 13a). The r^2 values in the present case suggests a relatively weak relationship between younger and older RTs as practice progresses. On the target-present trials, older adults were doing as well as younger adults as suggested by the negative slope, while on target-absent trials, older adults were performing more slowly.

Table 47a.

Analysis of Variance for Average Fixation Duration Session 12.

Source	df	F	p
Age	1, 16	5.12	.037
Display Size	2, 32	36.02	< .001
Presence	1, 16	.95	.343
Age X Display Size	2, 32	1.77	.195
Age X Presence	1, 16	1.98	.177
Display Size X Presence	2, 32	2.74	.081
Age X Display Size X Presence	2, 32	5.66	.008

Table 47b.

Analysis of Variance for Average Fixation Duration on Target Present Trials in Session 12.

Source	df	F	p
Age	1, 16	27.52	< .001
Display Size	2, 32	1.53	.234
Age X Display Size	2, 32	.65	.508

Table 47c.

Analysis of Variance for Average Fixation Duration on Target Absent Trials in Session 12.

Source	df	F	p
Age	1, 16	19.26	< .001
Display Size	2, 32	3.93	.051
Age X Display Size	2, 32	2.22	.146

Table 48.

Analysis of Variance for Selection Factor Session 12.

Source	df	F	p
Age	1, 16	.64	.437
Display Size	2, 32	23.48	< .001
Presence	1, 16	40.35	< .001
Age X Display Size	2, 32	.58	.549
Age X Presence	1, 16	.61	.445
Display Size X Presence	2, 32	.90	.404
Age X Display Size X Presence	2, 32	.15	.822

This follows the same generalized slowing pattern seen Training Period 1 (Figure 5) and 2 (Figure 7), where target-absent trials have larger slopes.

The fixation number data (Figure 13b) shows a similar relationship to RT. No clear slowing pattern exists for either target-absent or target-present trials. However, recall that generalized slowing predicts no relationship between age and fixation number.

Reversal 3.

RT - In contrast to Reversal 2, Figure 14a shows both age groups showed some disruption in performance. However, there were no significant effects suggesting that reversal did not disrupt performance (Table 49).

Fixation Number – Shown in Figure 14b, both age groups showed some disruption at reversal. However, only the three-way interaction was significant (Table 50a). Simple effects for target-presence revealed that on target-present trials (Table 50b), younger adults showed more disruption as display size increased, whereas older adults showed less disruption. In comparison, on target-absent trials (Table 50c), there was no Age X Display Size interaction.

First Fixation Duration – As shown in Figure 14c, little or no disruption is evident in first fixations and in some cases, first fixations durations declined. Shown in Table 51, no effects were significant.

Average Fixation Duration – Similar to first fixations, average fixations showed little or no disruption (see Figure 14d). Again, no effects were significant (Table 52).

Selection Factor – The data for the selection factor is presented in Figure 14e. Again little or no disruption is evident. No age effects were significant, however, less

Table 49.

<u>Analysis of Variance for RT Reversal 3.</u>

Source	df	F	p
Age	1, 17	1.61	.221
Display Size	2, 34	1.55	.232
Presence	1, 17	1.32	.266
Age X Display Size	2, 34	3.08	.078
Age X Presence	1, 17	1.93	.183
Display Size X Presence	2, 34	1.36	.27
Age X Display Size X Presence	2, 34	1.07	.347

Table 50a.

Analysis of Variance for Fixation Number Reversal 3.

Source	df	F	p
Age	1, 16	.21	.654
Display Size	2, 32	.68	.492
Presence	1, 16	.42	.528
Age X Display Size	2, 32	3.25	.061
Age X Presence	1, 16	.43	.52
Display Size X Presence	2, 32	.38	.681
Age X Display Size X Presence	2, 32	3.29	.052

Table 50b.

Analysis of Variance for Fixation Number for Target Present Trials Reversal 3.

Source	df	F	p
Age	1, 16	.53	.476
Display Size	2, 32	.07	.873
Age X Display Size	2, 32	5.07	.024

Table 50c.

Analysis of Variance for Fixation Number for Target Absent Trials Reversal 3.

Source	df	F	p
Age	1, 16	.00	.945
Display Size	2, 32	1.40	.262
Age X Display Size	2, 32	.30	.703

Table 51.

Analysis of Variance for First Fixation Duration Reversal 3.

Source	df	F	p
Age	1, 17	.48	.499
Display Size	2, 34	.20	.816
Presence	1, 17	1.70	.209
Age X Display Size	2, 34	.15	.854
Age X Presence	1, 17	.00	.978
Display Size X Presence	2, 34	2.27	.141
Age X Display Size X Presence	2, 34	1.98	.172

Table 52.

Analysis of Variance for Average Fixation Duration Reversal 3.

Source	df	F	p
Age	1, 17	.62	.441
Display Size	2, 34	.27	.728
Presence	1, 17	1.04	.322
Age X Display Size	2, 34	.09	.883
Age X Presence	1, 17	.40	.535
Display Size X Presence	2, 34	1.03	.356
Age X Display Size X Presence	2, 34	.97	.376

Table 53.

Analysis of Variance for Selection Factor Reversal 3.

Source	df	F	p
Age	1, 16	.21	.654
Display Size	2, 32	10.26	.001
Presence	1, 16	4.00	.063
Age X Display Size	2, 32	.02	.962
Age X Presence	1, 16	.22	.643
Display Size X Presence	2, 32	2.65	.105
Age X Display Size X Presence	2, 32	.69	.468

disruption was found for Display Size 12 and there was a marginal effect of target-presence with less disruption on target-present trials (Table 53).

First Training Session (Session 13) – Training Period 4.

Accuracy – Figure 15a reveals that again target-present trials produced more errors than target-absent trials, and errors increased with display size (Table 54). As well, on target-present trials, errors increased particularly when display size was 24, but this increase in error did not occur on target-absent trials. No other effects were significant.

RT – The RT demonstrate patterns similar to previous sessions (Figure 15c). As shown in Table 55a, older adults were slower than younger adults, target-absent trials were slower compared to target-present trials, and RT increased as display size increased. Older adults were also slower at greater display sizes and on target-absent trials. Target-absent trials were also significantly slower than target-present trials as display size. The three-way interaction was also significant.

Post hoc tests again revealed similar patterns to those reported above. On target-present trials (Table 55b), both age groups performed comparably, but older adults had more difficulty on target-absent trials as display size increased. On target-present trials, (Table 55c) near zero slopes were evident for both younger adults (5.97 ms/item) and for older adults (7.47 ms/item), however on target-absent trials, whereas search for younger adults were still near parallel (10.70 ms/item), older adult (31.11 ms/item) slopes still suggested serial processing.

Fixation Number – Shown in Figure 15e, more fixations were made by older adults, on target-absent trials, and increased as display size increased. Older adults also

Table 54.

Analysis of Variance for Accuracy Session 13.

Source	df	F	p
Age	1, 17	2.74	.116
Display Size	2, 34	3.46	.06
Presence	1, 17	16.84	.001
Age X Display Size	2, 34	.05	.9
Age X Presence	1, 17	1.25	.279
Display Size X Presence	2, 34	4.65	.028
Age X Display Size X Presence	2, 34	.99	.361

Table 55a.

Analysis of Variance for RT Session 13.

Source	df	F	p
Age	1, 17	42.57	< .001
Display Size	2, 34	55.37	< .001
Presence	1, 17	50.96	< .001
Age X Display Size	2, 34	8.72	.005
Age X Presence	1, 17	17.92	.003
Display Size X Presence	2, 34	23.18	< .001
Age X Display Size X Presence	2, 34	10.52	< .001

Table 55b.

Analysis of Variance for RT on Target Present Trials in Session 13.

Source	df	F	p
Age	1, 17	36.10	<.001
Display Size	2, 34	11.01	.001
Age X Display Size	2, 34	.34	.631

Table 55c.

Analysis of Variance for RT on Target Absent Trials in Session 13.

Source	df	F	p
Age	1, 17	41.80	< .001
Display Size	2, 34	61.43	< .001
Age X Display Size	2, 34	14.68	< .001

made more fixations on target-absent trials, and more fixations were also made as display size increased for target-absent trials relative to target-present trials (Table 56a). Moreover the three-way interaction was significant.

Again on target-present trials (Table 56b), there was no age difference as a function of display size (Young = .04 fixations/item; Old = .01 fixations/item). However, on target-absent trials (Table 56c), the Age X Display Size interaction was marginally significant ($\underline{p}$ = .05) suggesting that older adults made slightly more fixations as display size increased on target-absent trials (.11 fixations/item) compared to younger adults (.06 fixations/item).

First Fixation Duration - The data for first fixation duration is graphed in Figure 16a, and show significant main effects for age, display size, and target-presence as shown in Table 57. Older adults had longer first fixations than younger adults; first fixations also increased as display size increased and were longer on target-present trials. No other effects were significant.

Average Fixation Duration – Shown in Figure 16c, on average, older adults had longer fixations (Table 58). Average fixation durations were longer on target-present trials, and decreased as display size increased. Higher-order effects were not significant.

Selection Factor – As shown in Figure 16e, similar to previous sessions, no age differences were found, but there was a significant effect of display size and target-presence (Table 59). That is, the selection factor decreased as display size decreased and was lower on target-absent trials.

Table 56a.

Analysis of Variance for Fixation Number Session 13.

Source	df	F	p
Age	1, 16	12.05	.003
Display Size	2, 32	25.81	< .001
Presence	1, 16	60.33	< .001
Age X Display Size	2, 32	.38	.629
Age X Presence	1, 16	17.92	.003
Display Size X Presence	2, 32	27.80	< .001
Age X Display Size X Presence	2, 32	10.35	.001

Table 56b.

Analysis of Variance for Fixation Number on Target Present Trials in Session 13.

Source	df	F	p
Age	1, 17	6.97	.017
Display Size	2, 34	4.43	.039
Age X Display Size	2, 34	.95	.362

Table 56c.

Analysis of Variance for RT on Target Absent Trials in Session 13.

Source	df	F	p
Age	1, 17	17.03	.001
Display Size	2, 34	41.66	< .001
Age X Display Size	2, 34	3.62	.05

Table 57.

Analysis of Variance for First Fixation Duration Session 16.

Source	df	F	p
Age	1, 18	4.60	.046
Display Size	2, 36	30.48	< .001
Presence	1, 18	.53	.475
Age X Display Size	2, 36	.29	.729
Age X Presence	1, 18	.30	.593
Display Size X Presence	2, 36	.16	.820
Age X Display Size X Presence	2, 36	.77	.452

Table 58.

Analysis of Variance for Average Fixation Duration Session 16.

Source	df	F	p
Age	1, 17	7.98	.012
Display Size	2, 34	5.01	.028
Presence	1, 17	1.25	.278
Age X Display Size	2, 34	.65	.465
Age X Presence	1, 17	3.88	.065
Display Size X Presence	2, 34	.59	.524
Age X Display Size X Presence	2, 34	.71	.469

Table 59.

Analysis of Variance for Selection Factor Session 16.

Source	df	F	p
Age	1, 16	.32	.582
Display Size	2, 32	45.36	<.001
Presence	1, 16	14.57	.001
Age X Display Size	2, 32	1.39	.264
Age X Presence	1, 16	.95	.351
Display Size X Presence	2, 32	1.02	.361
Age X Display Size X Presence	2, 32	2.13	1.45

Last Session Training (Session 16) – Training Period 4.

Accuracy – Table 60 reveals a marginal effect of age, with younger adults committing more errors than older adults (Figure 15b). As well, target-present trials produced more errors than target-absent trials. The Display Size X Target-Presence interaction was also significant, with errors increasing with display size on target-present trials, but not for target-absent trials. No other effects were significant.

RT - The pattern in RT data from previous sessions persisted to the last training session. As shown in Figure 15c and 15d, RT continued to decrease as a result of practice. All main effects were significant (Table 61a). Older adults again had slower RTs on target-absent trials and showed a greater display size effect. No Age X Display Size effect was found, however, the three-way interaction was again significant.

Post hoc analyses showed that on target-present-trials (Table 61b), younger adults and older adults performed comparably as a function of display size (although this was marginally significant, $p = .047$). However, older adults still showed a significantly greater display size effect relative to younger adults on target-absent trials (Table 61c).

Display size slopes again showed that while automatic processing was evident for younger adults for both target-present (3.57 ms/item) and target-absent (6.46 ms/item) trials, for older adults, automatic processing was only evident on target-present trials (6.58 ms/item). On target-absent trials, display size slopes still indicated controlled processing for older adults (21.56 ms/item).

Fixation Number – The pattern exhibited by the fixation number data also persisted throughout training (Table 62a). As shown in Figure 15f, older adults made more fixations and more fixations were made on target-absent trials. Fixations also

Table 60.

Analysis of Variance for Accuracy Session 16.

Source	df	F	p
Age	1, 18	3.6	.074
Display Size	2, 36	.12	.884
Presence	1, 18	7.90	.012
Age X Display Size	2, 36	.32	.721
Age X Presence	1, 18	.07	.798
Display Size X Presence	2, 36	4.43	.028
Age X Display Size X Presence	2, 36	.42	.615

Table 61a.

Analysis of Variance for RT Session 13.

Source	df	F	p
Age	1, 18	45.03	< .001
Display Size	2, 36	63.30	< .001
Presence	1, 18	49.37	<.001
Age X Display Size	2, 36	14.25	< .001
Age X Presence	1, 18	16.93	.001
Display Size X Presence	2, 36	23.28	< .001
Age X Display Size X Presence	2, 36	10.83	.001

Table 61b.

Analysis of Variance for RT on Target Present Trials in Session 16.

Source	df	F	p
Age	1, 18	42.03	< .001
Display Size	2, 36	37.24	< .001
Age X Display Size	2, 36	3.37	.047

Table 61c.

Analysis of Variance for RT on Target Absent Trials in Session 16.

Source	df	F	p
Age	1, 18	41.43	< .001
Display Size	2, 36	50.29	< .001
Age X Display Size	2, 36	14.67	< .001

Table 62a.

Analysis of Variance for Fixation Number Session 16.

Source	df	F	p
Age	1, 17	13.60	.002
Display Size	2, 34	27.19	< .001
Presence	1, 17	50.88	< .001
Age X Display Size	2, 34	1.67	.207
Age X Presence	1, 17	15.98	.001
Display Size X Presence	2, 34	18.65	< .001
Age X Display Size X Presence	2, 34	9.53	.001

Table 62b.

Analysis of Variance for Fixation Number on Target Present Trials in Session 16.

Source	df	F	p
Age	1, 17	8.19	.011
Display Size	2, 34	4.14	.032
Age X Display Size	2, 34	.39	.649

Table 62c.

Analysis of Variance for Fixation Number on Target Absent Trials in Session 16.

Source	df	F	p
Age	1, 17	16.90	.001
Display Size	2, 34	46.33	< .001
Age X Display Size	2, 34	7.84	.003

increased as display size increased. Similar to RT, the Age X Display Size effect was not significant. However, older adults still made more fixations on target-absent trials and more fixations were made as display size increased. The three-way interaction was again significant.

On target-present trials (Table 62b), no Age X Display size interaction was found (Young = .02 fixations/item: Old = .10 fixations/item), however on target-absent trials (Table 62c), older adults still made more fixations with display size (.08 fixations/item) relative to younger adults (.03 fixations/item).

First Fixation Duration – Shown in Figure 16b, older adults continued to have longer first fixations and first fixations were longer as display size increased (Table 63). No other effects were significant.

Average Fixation Duration – As shown in Figure 16d, the pattern for average fixation duration persisted throughout practice. Average fixation duration decreased relative to Session 13, especially for older adults (Table 64). Still, older adults made longer fixations than younger adults and average fixations were shorter as display size increased.

Selection Factor – The pattern for the selection factor throughout training remained constant and no age differences were found as shown in Figure 16f. It continued to decline as display size increased and was higher on target-present trials (Table 65). No other effects were significant.

Generalized Slowing - Training Period 4.

Shown in Figure 17a, the r^2 values in the Brinley plot for RT suggests a moderate linear relationship in the target-present data and a strong linear relationship in the target-

Table 63.

Analysis of Variance for First Fixation Duration Session 16.

Source	df	F	p
Age	1, 18	4.60	.046
Display Size	2, 36	30.48	< .001
Presence	1, 18	.53	.475
Age X Display Size	2, 36	.29	.729
Age X Presence	1, 18	.30	.593
Display Size X Presence	2, 36	.16	.820
Age X Display Size X Presence	2, 36	.77	.452

Table 64.

Analysis of Variance for Average Fixation Duration Session 16.

Source	df	F	p
Age	1, 17	7.98	.012
Display Size	2, 34	5.01	.028
Presence	1, 17	1.25	.278
Age X Display Size	2, 34	.65	.465
Age X Presence	1, 17	3.88	.065
Display Size X Presence	2, 34	.59	.524
Age X Display Size X Presence	2, 34	.71	.469

Table 65.

Analysis of Variance for Selection Factor Session 16.

Source	df	F	p
Age	1, 16	.32	.582
Display Size	2, 32	45.36	< .001
Presence	1, 16	14.57	.001
Age X Display Size	2, 32	1.39	.264
Age X Presence	1, 16	.95	.351
Display Size X Presence	2, 32	1.02	.361
Age X Display Size X Presence	2, 32	2.13	1.45

absent data, although again, parameter estimates deviate from those usually found in generalized slowing analyses. In addition, once again, the fixation number data between the age groups are also moderately related (Figure 17b). Although the r^2 value is smaller than what is expected by generalized slowing, it is still suggestive of a strong relationship between younger and older adult fixation numbers, which is not predicted by generalized slowing.

Examining the Effects of Education

Recall that earlier demographic analyses found that older adults, on average, had less education than younger adults. Thus, to further analyze this potential problem, years of education was included as a variable to investigate its possible role as a confounding factor in the present study. This was performed by submitting display size slopes for each of the above dependent measures to a three-way split-plot Age (2) X Education (2) X Presence (2) ANOVA. Those participants who had 16 years of education or more (n = 11; 8 young, 3 old) were placed in the high education group and those who had less than 16 years of education were placed in the low education group (n = 9; 2 young, 7 old).

Although, several significant effects were found with years of education factoring into the effect (Table 66), only RT shows systematic effect. As shown in Figure X (b, j, & j), in Sessions 4, 9, and 13, the Education X Presence interaction suggests that while education has little effect on target-present trials, those with more education demonstrate a reduced slope on target-absent trials compared to those with less education.

This finding poses some difficulty for the interpretation of age effects in previous analyses. It might be then that the present age differences in visual search result from fewer years of education among the older participants. Although this possibility cannot

Table 66.

Significant Effects with Years of Education Included in Analysis of Variance

Session	Dependent Measure	Source	df	F
1	First Fixation Duration	Education X Presence	1, 16	9.01**
		Age X Education X Presence	1, 16	5.92*
4	Reaction Time	Education X Presence	1, 16	11.02**
		Age X Education X Presence	1, 16	8.86**
	Fixation Number	Age X Education X Presence	1, 16	6.33*
5	Average Fixation Duration	Education X Presence	1, 16	6.06*
8	Fixation Number	Education X Presence	1, 16	4.31*
9	Accuracy	Education	1, 16	8.65**
	Reaction Time	Education	1, 16	4.55*
		Education X Presence	1, 16	5.44*
12	First Fixation Duration	Education X Presence	1, 16	7.12*
		Age X Education X Presence	1, 16	7.77*

* $p < .05$: ** $p < .01$; *** $p < .001$

Table 66 cont'd

Significant Effects with Years of Education Included in Analysis of Variance

Session	Dependent Measure	Source	df	F
	Selection Factor	Education X Presence	1, 16	44.75***
		Age X Education X Presence	1, 16	24.64***
13	Reaction Time	Education X Presence	1, 15	6.23*
16	Average Fixation Duration	Age X Education	1, 16	5.01*

* p < .05; ** p < .01; *** p < .001

be ignored, and suggests that the present data be interpreted with some degree of cautiousness, there are several factors that also must be considered.

First, the effect of education with RT is not consistent throughout training. Unlike age, education was only significant in three sessions. Second, an examination of Figure 18 shows neither any systematic effect along any other dependent measure nor is there any systematic pattern across any of the dependent measures. Unlike the previous analyses, RT and fixation number closely paralleled each other. This suggests that although years of education may play a role in skill acquisition, the lack of any strong systematic relationship leaves the data questionable.

Discussion

Younger and older adults improved with CM training as demonstrated in the reduction in both overall RT and the display size effect. Evidence for automatic processing was illustrated on target-present data wherein the display size slopes for both groups were near zero, suggesting a parallel search of the display. As well, fixation number for both groups decreased with practice, but average fixation duration and first fixation duration remained relatively stable.

The inclusion of eye movement data allowed for evidence of feature-based selectivity in search. The selection factor data suggested that from the onset of training, participants were able to attend to items sharing the target's luminance contrast and this selectivity remained constant throughout training. Previous evidence for feature-based selectivity using luminance contrast or colour has been reported. Scialfa, et al. (in press) and Scialfa and Joffe (1998) both found that participants learned to quickly attend to white objects when the target was also white. Similarly, Reingold and Williams (1997) reported feature-based selectivity for colour when participants were presented with items defined by their colour and orientation.

Contrary to previous reports, (e.g., Scialfa et al., in press) the selection factor was not disrupted at reversal. The lack of disruption in the selection factor poses difficulty for strength theory, holds that after training, attention-attraction strength will be greatest for the target. Upon reversal, this would be the white objects. However, clearly participants were able to almost immediately select on black objects.

Several explanations can account for this. First, perhaps the amount of training given in the present study did not produce sufficient attention-attraction strength to the white objects such that performance became automatic. However, much of the data casts doubt on this view. For instance, the selection factor was consistently high and in favour of white objects throughout Training Period 1. As well, the disruption in RT and fixation number provided some evidence of automatic processing and the reduction in display size at the end of training suggests that performance became near automatic.

Second, the ability to modify attention-attraction strength may occur very rapidly, such that it was undetected by the selection factor data. That is, if modification of attention-attraction strength occurred within the first few trials after reversal, it may not have affected the selection factor. If this is true, strength theory must account for this quick, efficient and flexible system. Schneider (1985) does suggest that both associative and priority learning begin immediately after the first correct response. However, the stage model proposed by Schneider does not explicitly allow for such quick priority learning. Moreover, if such a quick and efficient modification of priority learning is possible, it does not explain the disruption of RT and fixation number.

To examine this possibility, the selection factor data was resubmitted to a split-plot Age (2) X Display Size (3) X Target Presence (2) X Blocks (8) ANOVA for Session 1 and Session 5. If priority-learning occurs very quickly within a session, examining the selection factor blockwise within a session may reveal improvement in priority learning as the session progressed. Session 1 was chosen because attention-attraction strength should have been equally distributed across the stimuli initially. As well, Session 5 was reanalyzed because there was significant disruption in RT and fixation number suggesting that could have been some disruption in priority-learning.

However, in both sessions, the selection factor did not change across blocks (p > .2), nor did it interact with any of the other variables (p > .13). In fact, even on the first block, the selection factor was considerably high (.79 and .70 for Session 1 and Session 5, respectively) suggesting that participants directed attention to target-like luminance contrast immediately. This more convincingly suggests that it is not the case that priority learning is a quick, very efficient type of learning, but instead, participants may be using some form of rule-based strategy to perform the task.

This third possibility, that the flexibility of feature-based selection could suggest evidence for rule-based learning had been alluded to previously. Participants may be able to adopt a simple algorithm (i.e., look for objects that share a target's luminance contrast and perform a search on only those objects) which would allow for quick and efficient search of a display regardless of whether the stimuli are reversed. The final suggestion does coincide with participant reports of how search became easier with practice. Although participants generally seemed unaware of any overt strategy, many reported that as training progressed, "white lines [when looking for a white target] seemed to stand out" or that "black lines were ignored as if they weren't there". However, once again, rule-based learning does not explain why there was evidence of disruption in RT and fixation number. Additional discussion on rule-based learning will be deferred until later.

Last, top-down activation may very well be flexible, but at reversal, participants scanned fewer items per fixation to maintain high accuracy. That is, rather than scanning the entire display in parallel, they performed a serial search on small groups of items in the display. This is tantamount to extending the group-scanning hypothesis (Triesman & Gormican, 1988) to conjunction search as suggested by Scialfa and Joffe (1998). Unlike the previous explanations, this explanation would account the increase in fixation number and RT, while the selection factor would remain unaffected.

The group-scanning hypothesis can also account for how eye movements are affected with practice. With training, fixation numbers decreased, however average fixation duration and first fixation duration remained relatively stable throughout. This suggests that at each fixation, participants were able to process more information in the same amount of time. A group-scanning account would argue that participants were able to increase the number of scanned items at each fixation, until eventually, the entire display could be processed in parallel. Age differences may be accounted for by arguing that older adults are less able to expand the number of scanned items per fixation. Certainly this is consistent with previously reported age deficits in the UFOV (Ball et al., 1988; Scialfa, et al., 1994).

The Effects of Practice and Aging

Priority-Learning Deficit Hypothesis

RT and fixation number for both younger and older adults decreased with practice and on average, older adults consistently had longer RTs and more fixations than younger adults. Table 67 and 68 outlines those hypotheses that were supported and not supported. At first glance, this trend appears to support the priority-learning deficit hypothesis. However, several other pieces of evidence reveal that this is an oversimplification.

First, a consistent finding throughout this study was a three-way interaction on RT and fixation number. Display size slopes for RT and fixation number for target-present trials suggested trivial display size effects for both age groups. However, on target-absent trials, display size slopes for older adults were consistently greater than that of younger adults. If older adults have a priority learning deficit, this deficit should occur on both target-absent and target-present trials.

Second, if older adults had a priority-learning deficit, allocation of attention would be expected to be more haphazard. Instead, the lack of any age difference on the selection factor suggests that priority learning for older adults is as efficient as for younger adults. This observation has previously been reported. Scialfa et al. (in press) presented their participants with similar conjunction displays and found that older adults fixated on objects sharing the target's characteristics as frequently as younger adult.

Third, no age differences were found in the disruption data on any of the dependent measures. This suggests that older adults attained levels of automatic processing equivalent to their younger counterparts. If older adults had a priority learning deficit, they would be expected to show less disruption. Previous studies

Table 67. Hypotheses for older and younger adults for each dependent variable after initial practice according to strength theory and generalized slowing.

Dependent Measure	Strength Theory	Generalized Slowing
Young RT	Decrease	Decrease
Old RT	Decrease (Less)	Decrease (Less)
Young Fixation Duration	Unspecified	Shorter Fixations
Old Fixation Duration	Unspecified	Shorter Fixations (Greater)
Young Fixation Number	Fewer Fixations	Unspecified
Old Fixation Number	Fewer Fixations (Greater)	Unspecified (Equivalent)
Young Selection Factor	Bias target	Unspecified
Old Selection Factor	Bias target (Less)	Unspecified (Equivalent)

Note. Parenthesized words refer to the effect among older adults relative to younger adults. (Less) means older adults will have a lower value on the dependent variable. (Equivalent) means the predicted effect will be equal for the two age groups, and (Greater) means the older adults should have a higher value on the dependent measure. Solid line means the hypothesis was supported and dashed lines means the hypothesis was not supported.

Table 68. Hypotheses for disruption scores in older and younger adults for each dependent variable according to strength theory and generalized slowing.

Dependent Measure	Strength Theory	Generalized Slowing
Young RT	Increased RT	Increased RT
Old RT	Increased RT (Less)	Increased RT (Equivalent)
Young Fixation Duration	Unspecified	Longer Fixations
Old Fixation Duration	Unspecified (Less)	Longer Fixations (Equivalent)
Young Fixation Number	More Fixations	Unspecified
Old Fixation Number	More Fixations (Less)	Unspecified (Equivalent)
Young Selection Factor	Decreased Bias To Target	Unspecified
Old Selection Factor	Decreased Bias To Target (Less)	Unspecified (Equivalent)

Note. Parenthesized words refer to the effect among older adults relative to younger adults. (Less) means older adults will have a lower value on the dependent variable, (Equivalent) means the predicted effect will be equal for the two age groups, and (Greater) means the older adults should have a higher value on the dependent measure. Solid line means the hypothesis was supported and dashed lines means the hypothesis was not supported.

involving semantic category search, have shown older adults exhibit less disruption at reversal (Fisk, McGee, & Giambra, 1988; Fisk & Rogers, 1991; Gilbert & Rogers, 1996). The lack of an age difference in disruption casts some doubt on generalizing studies involving semantic category search to visual search.

The conclusions drawn by Fisk, Rogers, and their colleagues is not in dispute, but may be specific to semantic category search. It is acknowledged that semantic category search is a "more complex processing task than those tasks previously used to examine age influences on memory and visual search" (Fisk, McGee, & Giambra, 1988, p. 323) and it may be this additional complexity that results in age differences. As well, it was previously suggested that prior studies observing priority-learning deficits in the elderly also commonly employed a mixed design, whereby VM and CM training were frequently switched (Bailey & Lauber, 1998; Hahn, Kramer, deJong, Gopher, Minear, & Glass, 1998; Kray & Lindenberger, 1998). Hahn et al. (1998) found that older adults may have great difficulty in task switching under high memory load and practice did not eliminate this effect.

Combined, the display size slopes, the selection factor and the disruption data suggest an alternate explanation is needed for age differences in the acquisition of visual search skills. Cerella (1991) suggested that age differences in semantic category search could be accounted for by generalized slowing. Therefore, discussion will now focus on the generalized slowing hypothesis to see if it can provide a better account of the present data.

Generalized Slowing Hypothesis

As with strength theory, generalized slowing predicts that although both age groups will benefit from practice, older adults should still perform the task more slowly and this was evident in the present study. Moreover, generalized slowing predicts no age differences in disruption (as operationalized in the present study) on RT or average fixation duration and these predictions were supported. However, other findings cannot be accounted for by generalized slowing.

Parameter estimates deviated considerably from what is commonly reported by generalized slowing. Cerella (1991) examined slowing parameter estimates from 32 studies and found the 95% confidence interval for slopes ranged from 1.0 to 2.5 and for the intercept, ranged from approximately -500 to 100. In the present data slope estimates ranged from .86 to 3.2 and intercepts ranged from -948.92 to 464.18.

While this might only reflect differences in sampling variability, systematic patterns in the data suggest that this is not the case. Slope values were consistently greater on target-absent trials. If a single central processing mechanism is responsible for slowing, this slowing should not be affected by target presence. Instead, this suggests another factor may be needed to account for the age differences obtained.

Furthermore, the r^2 values in the present data also suggest that a single slowing factor is unable to account for the present data. Commonly, when RT data is plotted in a Brinley analyses, r^2 values are above .90. In the present data, r^2 values are considerably lower suggesting another factor may be needed to explain the unaccounted variance.

Why might there such a difference in the present data and the slowing data previously reported? Perhaps the effects of practice moderate the slope and the intercept in such a fashion that the slowing factor must be adjusted. Cerella (1991) replotted Fisk and Roger's (1991) data from one session in Brinley space, however, in the present study, data points over several sessions of practice were used. Thus, by analyzing sessions individually, the r^2 values may better conform to a slowing framework. To investigate this possibility, Brinley plots for RT and fixation number for the first and last session of each training period were replotted in Figure 19 and 20, respectively. As illustrated in the RT data, the r^2 values now conform to the slowing framework. In each case, r^2 values are near or above .90, suggesting that most of the variance can be accounted for by a single factor.

However, a closer examination of the RT plots (Figure 14) still reveals some problems for generalized slowing. A comparison of the slopes from the first session to the last session of each training period, suggests that as practice progresses, the slope increases. That is, although the speed of processing improves with practice, younger adults appear to be benefiting more. This is at odds with generalized slowing which assumes that the slowing factor is constant. Thus, the present data suggest that slowing factor is not constant and can be modified by both target-presence (above) and by practice.

Thus, the data suggests that age deficits in search cannot be explained by generalized slowing alone. The change in the slope with target-presence and practice, the low r^2 values when Brinley analyses are performed across sessions, and the relationship between RT and fixation number challenges the general slowing claim. Further evidence against generalized slowing is shown in the Brinley plots of fixation number (Figure 15).

Generalized slowing does not predict any age differences in fixation number, yet fixation number conforms to a linear function similar to RT.

Similar criticisms of Brinley analyses have been presented (Fisk et al., 1992; Perfect, 1994). Perfect (1994, p. 63) argued, "The usual [Brinley] analysis is to simply plot a large number of points from different studies and attempt to fit them with single functions. However....global functions are almost guaranteed". That is, Brinley analyses are often able to account for a great deal of variance, but they also conceal effects that are central to age differences. Or, perhaps as Scialfa and Joffe (1998) suggested, older adults have a general loss in search efficiency, of which slowing is one component.

The ANOVAs and the Brinley analysis indicate that another important factor in age-related differences is target presence. That is, performance deficits are more pronounced when older adults are faced with target-absent trials, suggesting that there is difficulty in making a decision when there is no target present. Several theories may provide insight into this effect by suggesting that older adults may simply be employing a more conservative response criterion.

Can Cautiousness Account for Age Differences In Search?

It has long been suggested that older adults use a more cautious approach in responding to tasks and this is reflected in a speed-accuracy tradeoff (Salthouse, 1979, 1982). In visual search, several researchers have suggested a response criterion or an activation threshold is needed to account for speed-accuracy tradeoffs (Humphrey and Müeller, 1993; Strayer & Kramer, 1994) and the termination of target-absent trials (e.g., Chun & Wolfe, 1996).

Chun and Wolfe (1996) asserted that participants only adjust their activation threshold on target-absent trials. On target-present trials, they found that whether the response was correct or incorrect, people did not adjust their speed of response. In contrast, on target-absent trials, after a correct response, subsequent target-absent trials were performed more quickly. If however, an incorrect response was made, the following target-absent trial was considerably longer. Chun and Wolfe (1996) argued that individuals employed a more conservative activation threshold when the errors occur on target-absent trials.

The accuracy analyses in the present study are consistent with this suggestion. Errors were consistently greater on target-present trials. This might suggest a less conservative response criterion when the signal is present. Moreover, although age differences in accuracy were rarely evident, when they did exist, they were in the direction suggesting that older adults were more cautious. Again, because errors were relatively low, it is difficult to address whether the lack of age differences were "real" or the result of ceiling effects.

If older adults are more concerned about their errors, then it is conceivable that they adjust their activation threshold (or response criterion) at an even more conservative level than younger adults. This has been suggested by Strayer and Kramer (1994) who found a speed-accuracy tradeoff in memory search. When accuracy was equated for younger and older participants, slope differences were reduced and transfer levels for both age groups were comparable.

To account for this, Strayer and Kramer (1994) adopted a model of skill acquisition that involves both a data-driven component and a strategic component. The data-driven component follows the strength theory of automaticity. That is, skill acquisition involves the transition from controlled to automatic processing as outlined by Schneider and Shiffrin (1977). The strategic component involves individual settings of response criteria that are influenced by instructions, motivation, and trial-by-trial feedback. Age differences in skill acquisition then result from a more conservative setting of response criteria.

If older adults are simply using a more conservative approach to responding, there is no reason why the degree of transfer should be any less for them. In the present study, no age differences in transfer were found. That is, both older and younger participants were able to perform equally well when searching for a white target or a black target. This contradicts previous findings that suggested age differences in transfer (e.g. Fisk et al., 1997). However, several differences between the current study and Fisk et al. (1997) may provide reasons for the conflicting data. First, as previously suggested, compared to a semantic category search, the present visual search task required fewer demands on working memory. Second, the retraining periods in the present study consisted of continuous CM training with a constant set of stimuli. In Fisk et al. (1997), transfer included several mixed conditions wherein the participant was required to switch from one set of stimuli to another. Therefore, the complexity of the procedure employed by Fisk et al. (1997) may have resulted in the age differences found.

Reversals and Transfer

The use of several reversal sessions provided greater evidence for non-specific learning in visual search. Although disruption was evident after the first reversal (Figure 5), participants were able to quickly adapt to the new target, and search efficiently. When reversal was again presented, both younger and older adults responded with little or no disruption (Figure 8). In fact, several measures indicated positive transfer rather than disruption. Upon the final reversal, although more disruption occurred on RT and fixation number than the previous reversal, the degree of disruption was still relatively small (Figure 11).

The positive transfer demonstrated in the present study presents some difficulty for strength theory. Schneider and Fisk (1984) argued that positive transfer was the result of spreading of activation to a superordinate node (e.g. searching for the word "blue", activates the "blue" node and a general "colour" node). Applying this explanation to the present study, during training, a superordinate node for luminance contrast was activated, which in turn activated both white and black objects simultaneously. However, the selection factor data clearly favour the target luminance contrast and thus are at odds with this explanation. Moreover, if both target and distractor luminance contrasts are activated, it is doubtful that participants would develop the high level of search efficiency seen in the present study.

The GSM2 may be more capable of explaining positive transfer. Recall that the GSM2 currently argues that top-down activation occurs in a categorical, broad-based manner. For instance, in the example used earlier, if participants are presented with a target line that is oriented at 20°, both a "steep" channel and a "right" channel would be activated. To accommodate for the present data, the GSM2 would have to allow for very efficient and flexible channels that can switch from a white target to a black target and vice versa. However, because GSM2 does not make any explicit predictions regarding the effects of practice, it is not clear whether this top-down activation would be this flexible after extensive practice.

The positive transfer seen here can also be accounted for with rule-based learning. Kramer, et al. (1990) argued that positive transfer could occur "as long as subjects can capitalize on the higher-order consistencies in a task". The strategic component of Strayer and Kramer's (1994) model was also used to explain the positive non-specific transfer evident in many skill acquisition studies. In their study (Strayer & Kramer, 1994), when participants were trained employing a CM blocked procedure, positive transfer was evident. They argued that participants were able to learn general rules that could apply to similar tasks involving different stimuli.

In the present study, perhaps participants learned to attend only to objects that shared the target's luminance contrast and then perform a subset search for orientation on the remaining items. Evidence for subset search has been demonstrated in other studies (Egeth, Virzi, & Garbart, 1984; Friedman-Hill & Wolfe, 1995). Friedman-Hill and Wolfe (1995) found that in a conjunction search display, participants could select on target-coloured items and perform a parallel search for the second feature.

Conclusions

The theoretical implications of the present data are numerous. Neither a priority-learning deficit nor generalized slowing did an adequate job of explaining the age differences (or the lack of some with respect to disruption) obtained. The priority-learning deficit hypothesis may be specific to semantic category search but fails to account for the lack of an age deficit on the selection factor or disruption found here. Generalized slowing also cannot explain the data without also incorporating an oculomotor component to explain the fixation number data and allowing for more flexibility in the slowing factor, which changes with practice effects and with target presence. It is suggested that older adults may simply be incorporating a more cautious approach in their response on target-absent trials. Moreover, evidence for positive transfer in later reversals suggests that either significant changes must be made in strength-based and activation models of search to account for the present data, or adopting a model such as the Strayer and Kramer's two-component model is necessary.

Future studies may want to investigate the mechanisms behind positive transfer in visual search. If positive transfer is the result of a spread of activation to other features along the same dimension (Fisk & Schneider, 1984; Sireteanu & Rettenbach, 1994), then training participants on a target with specific features should positively transfer to a new search task, provided that the featural dimension remains constant.

If rule-base transfer provides a more adequate explanation for positive transfer, then upon transfer, completely new stimuli composed of different featural dimensions should not greatly affect search performance. Thus, if participants were trained on conjunction task where the stimulus featural dimensions consisted of colour and orientation, a transfer condition in which the featural dimensions changed to shape and size should result in positive transfer.

Lastly, the stimuli do not necessarily need to be limited to only two featural dimensions. If participants are able to perform feature-based selection in a double-conjunction search, can this be generalized to a triple conjunction search? For example, if participants are presented with stimuli consisting of different colours, shapes, and orientations, can they select objects only consisting of the target's colour and shape, and then perform a search on the remaining objects' orientation? Furthermore, are older adults any less able to do this? Examining the restrictions of feature-based selection and aging will have several theoretical implications regarding the flexibility of top-down processing and provide more insight into the mechanisms behind age differences in search. Furthermore, by expanding the stimuli to more complex objects, it will provide a stronger basis for generalizing laboratory based visual search experiments to real world search.

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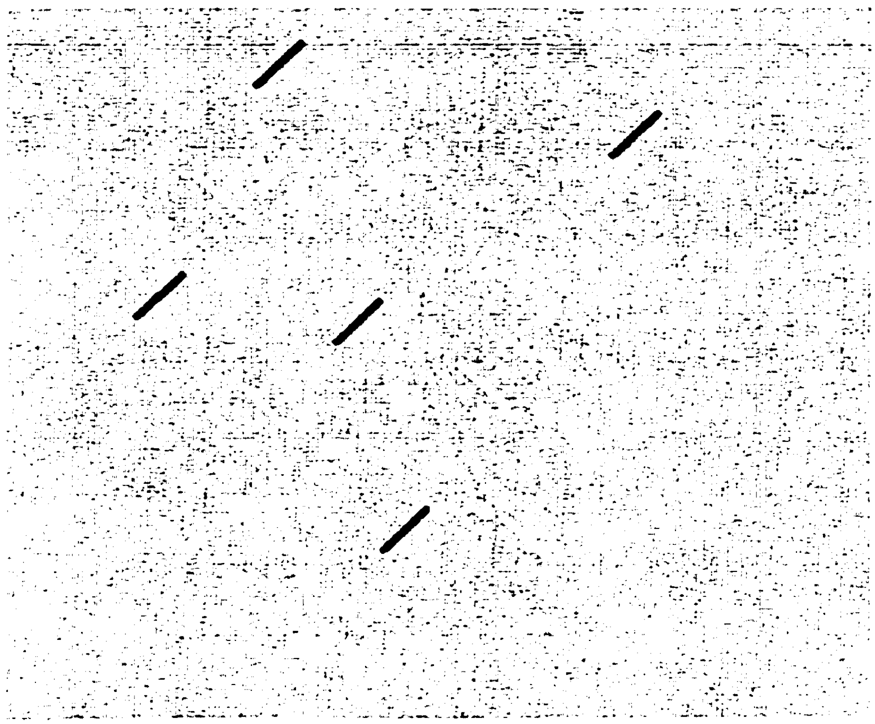


Figure 1. Example of conjunction search display with a white-right target used in Training Period 1 and Training Period 3.

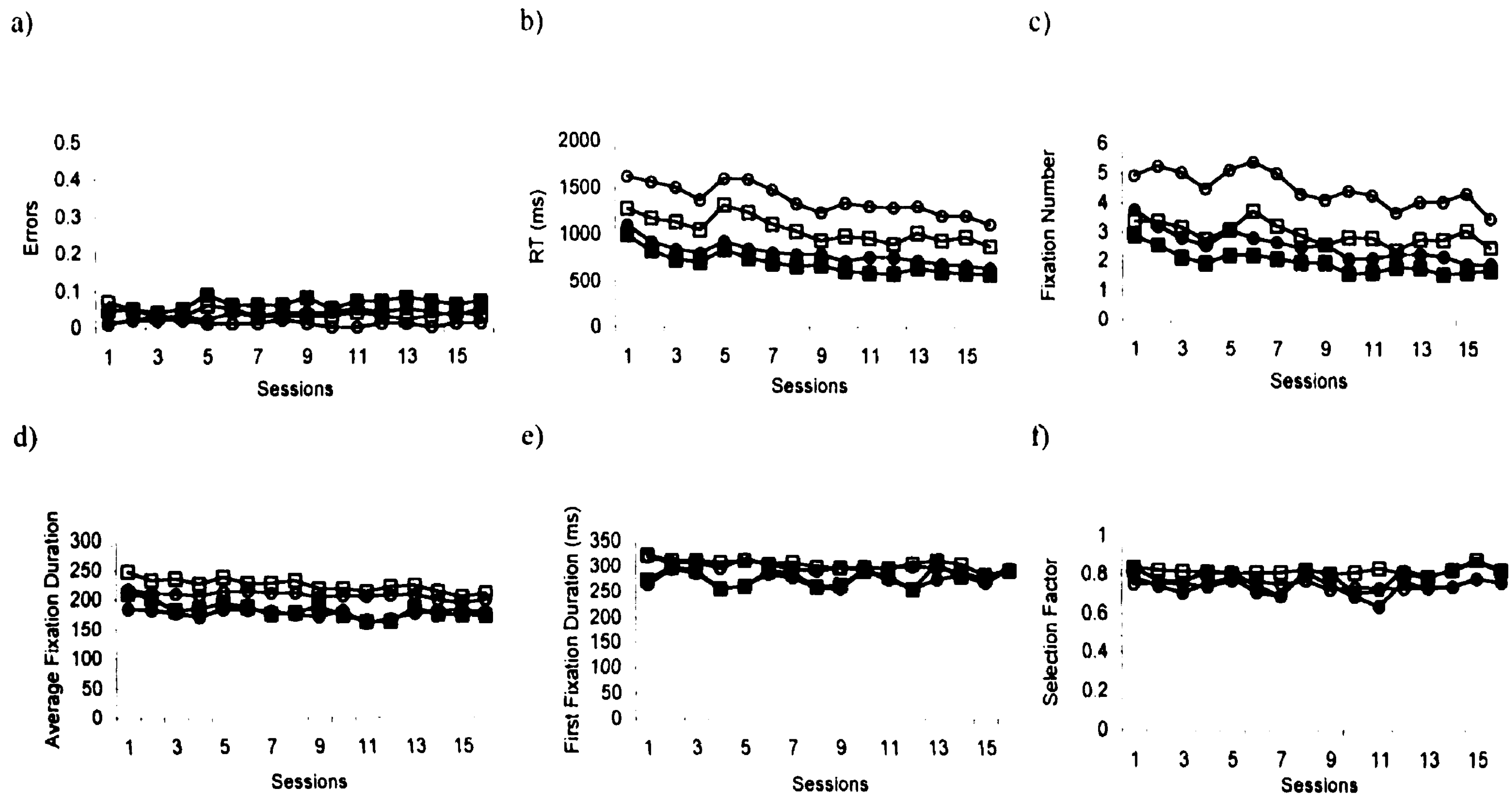


Figure 2. Performance across the entire 16 day session as a function of age and target-presence on a) accuracy b) RT c) fixation number d) first fixation duration e) average fixation duration and f) the selection factor.

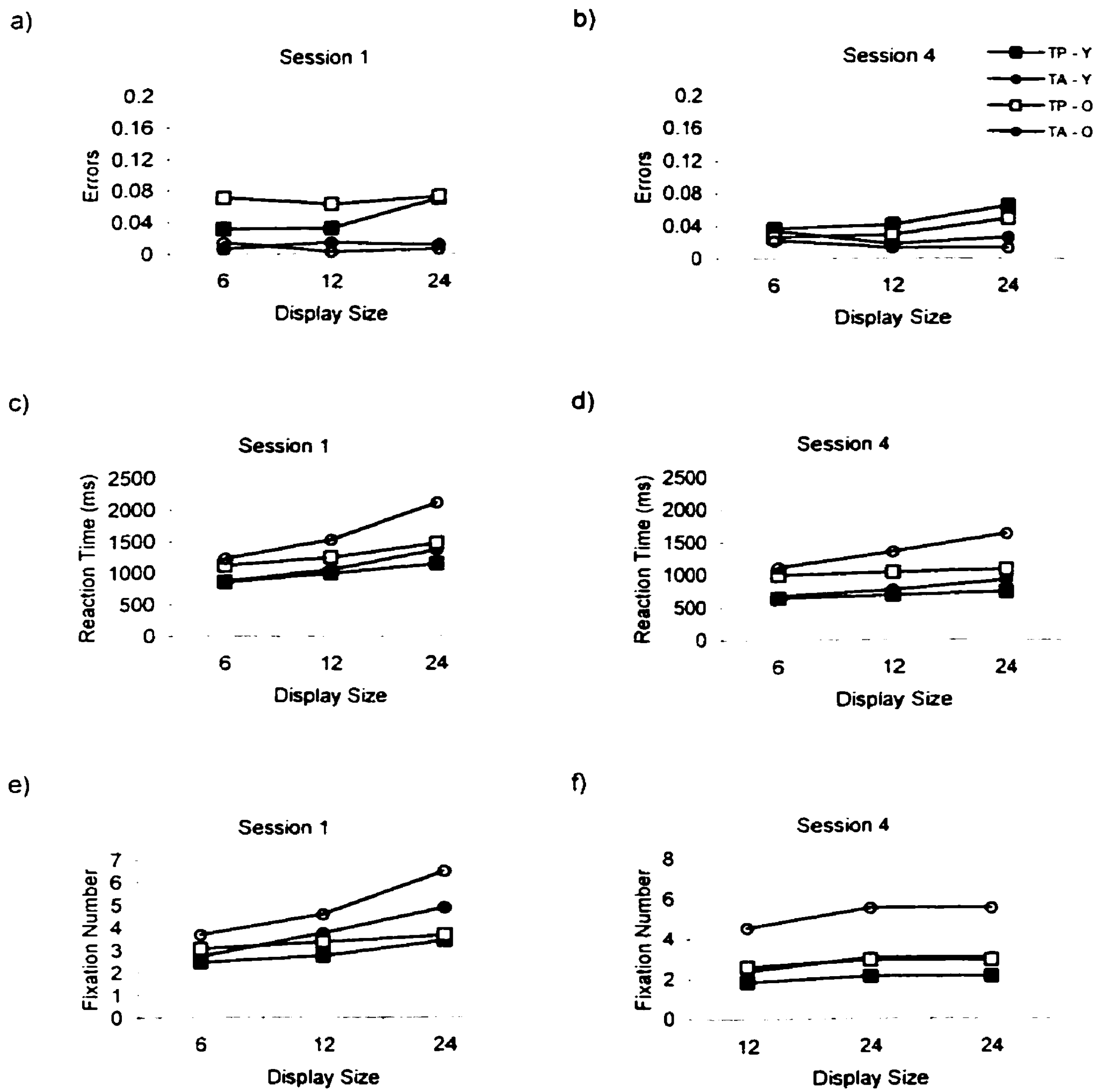
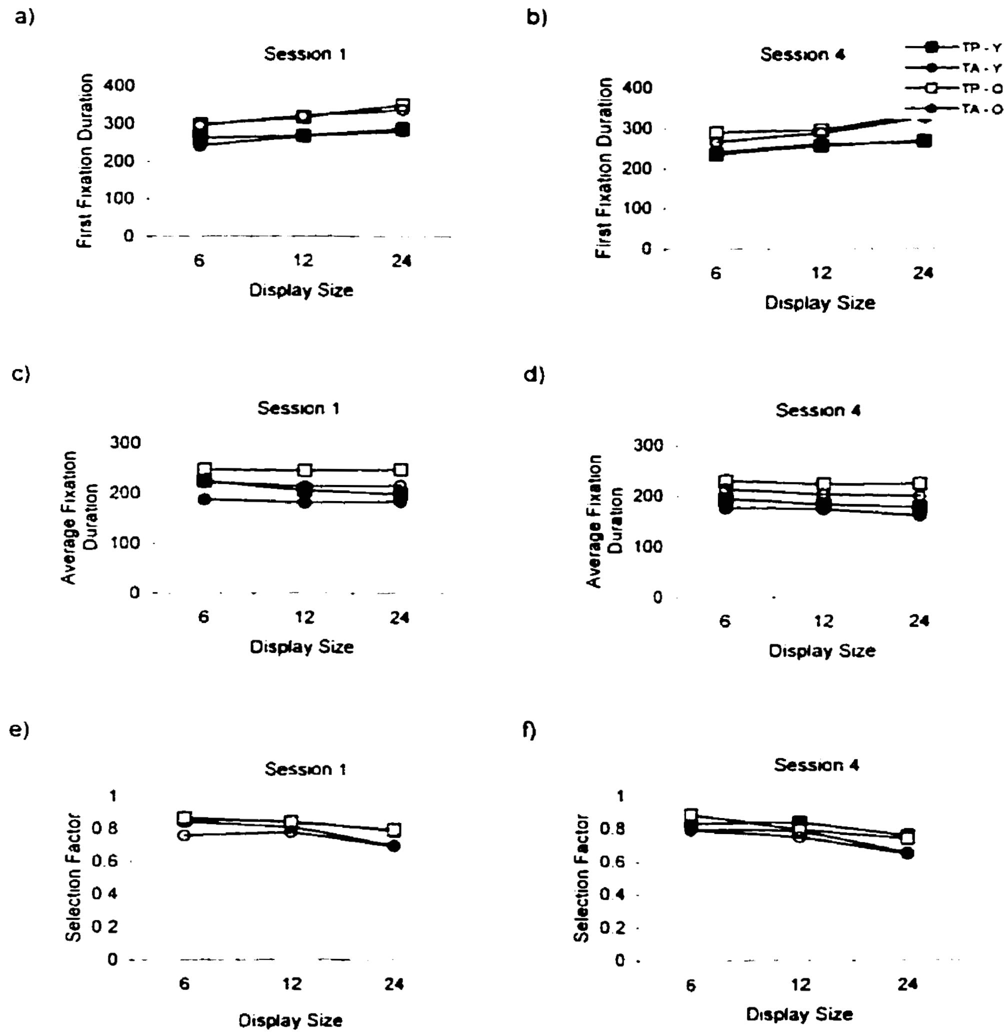


Figure 3. Conjunction search performance in Training Period 1 as a function of age, display size, and target-presence. Left panels, Session 1; Right panels, Session 4. From top to bottom: accuracy, RT and fixation number.



<u>Figure 4.</u> Conjunction search performance in Training Period 1 as a function of age, display size, and target-presence. Left panels, Session 1; Right panels, Session 4. From top to bottom: first fixation duration, average fixation duration, and the selecti factor.

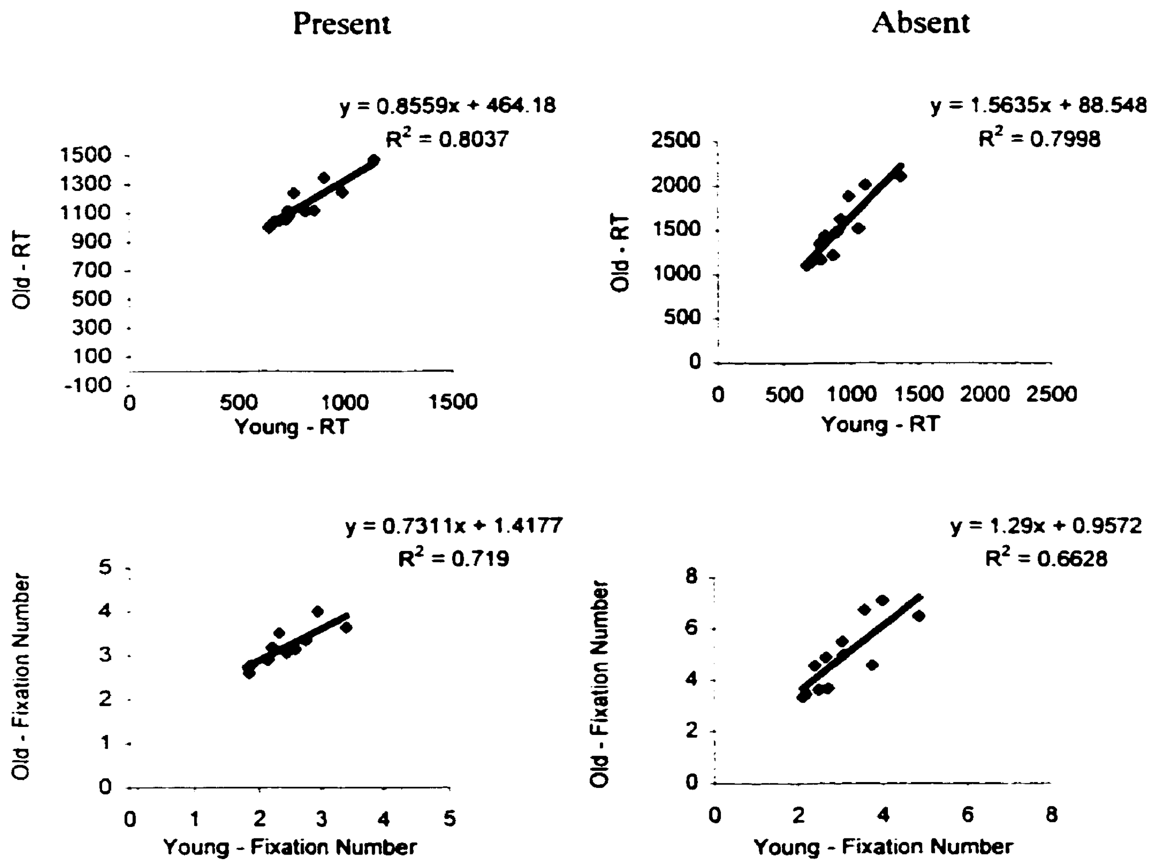


Figure 5. Brinley plots for target-present (left) and target-absent (right) trials Training Period 1. Older adults' RTs (top) and fixation number (bottom) are plotted as a function of younger adults'.

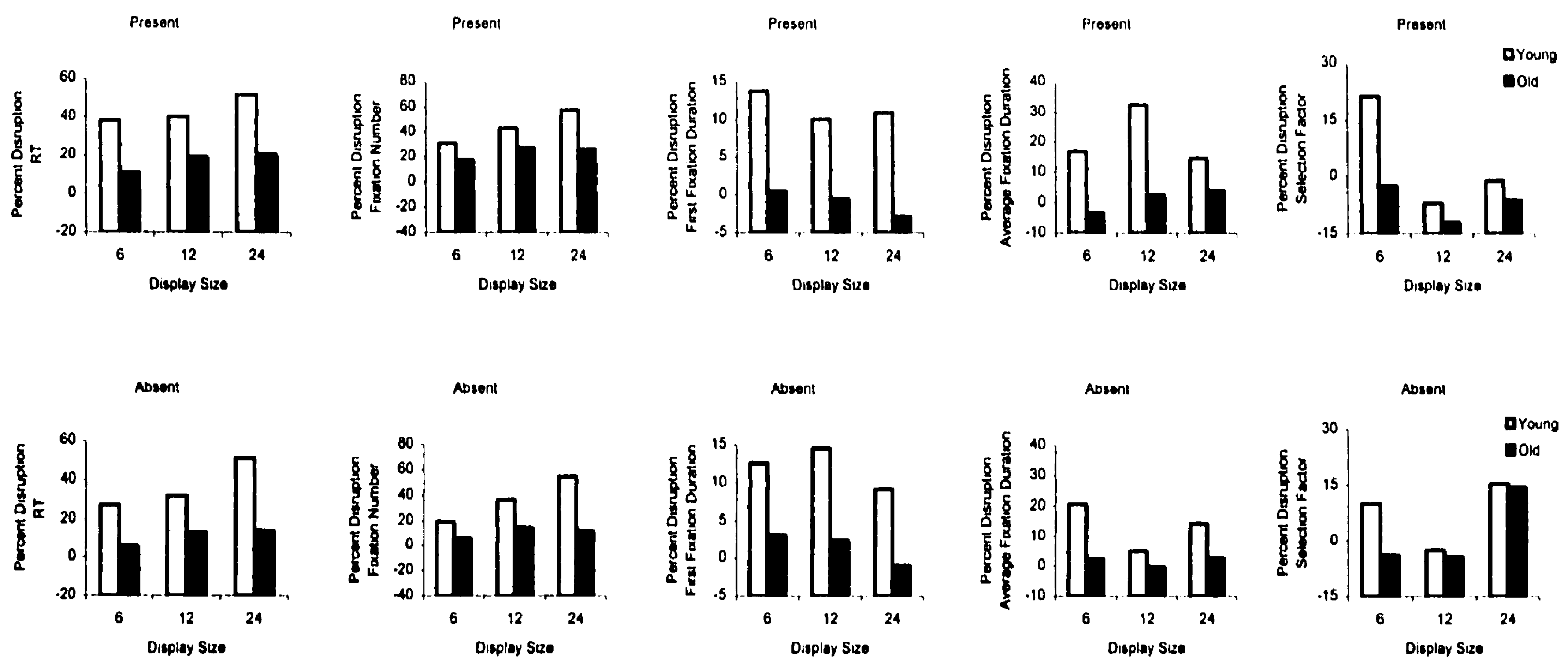


Figure 6. Disruption scores (Session 5 - Session 4/Session 4) after the first reversal for target-present (top-panel) and target-absent (bottom panel) trials as a function of age and display size. From left to right, the data are for RT, fixation number, first fixation duration, average fixation duratio and the selection factor.

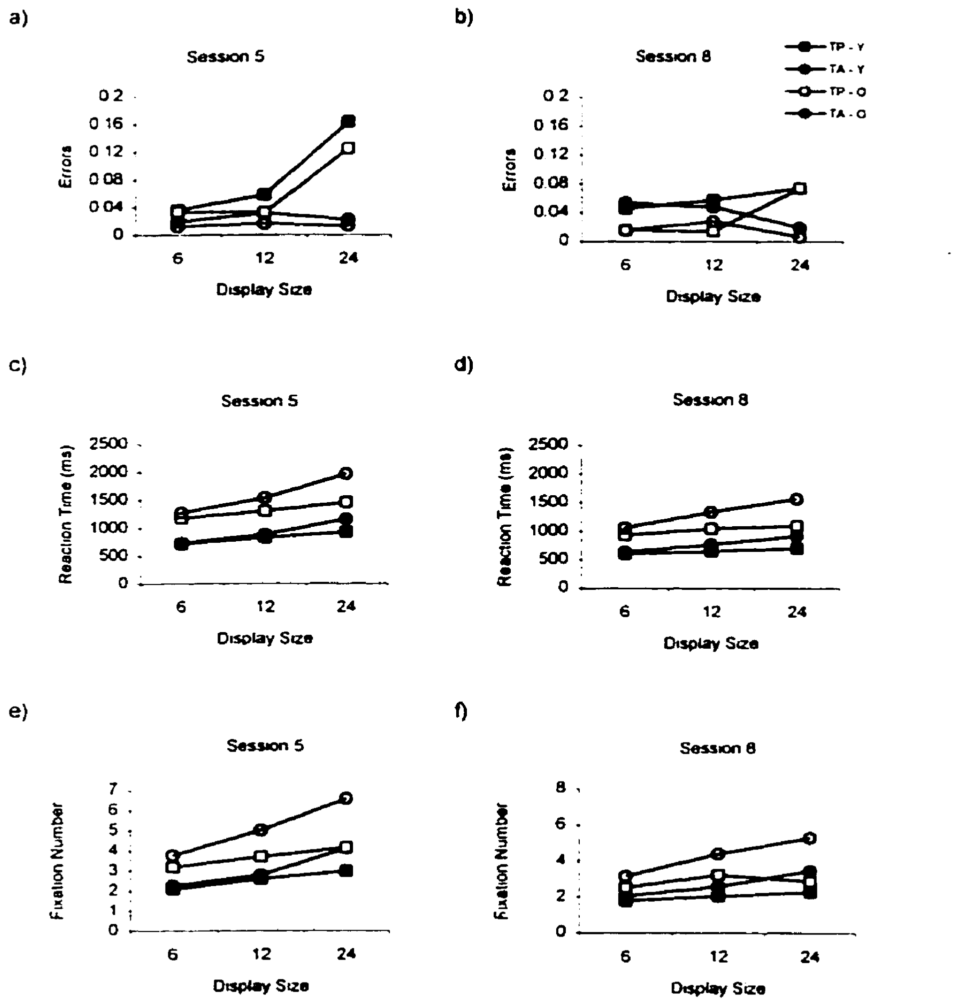


Figure 7. Conjunction search performance in Training Period 2 as a function of age, display size, and target-presence. Left panels, Session 5; Right panels, Session 8. From top to bottom: accuracy, RT, and fixation number.

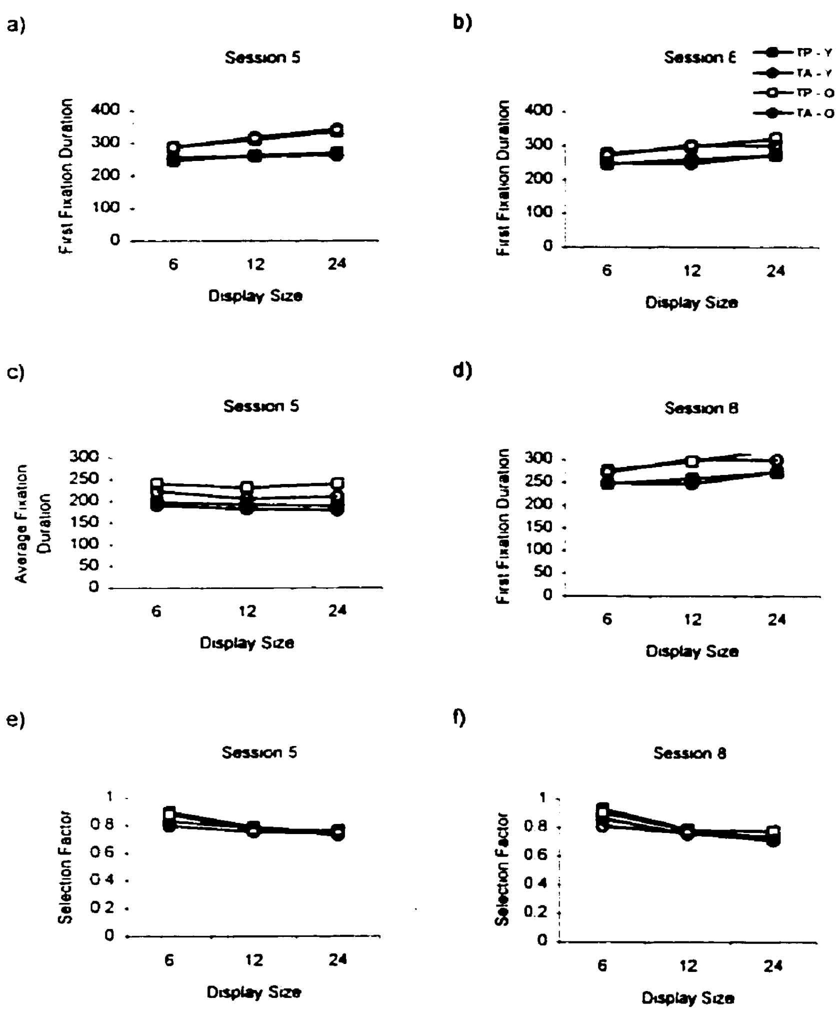


Figure 8. Conjunction search performance in Training Period 2 as a function of age, display size, and target-presence. Left panels, Session 5; Right panels, Session 8. From top to bottom: first fixation duration, average fixation duration, and the selection factor.

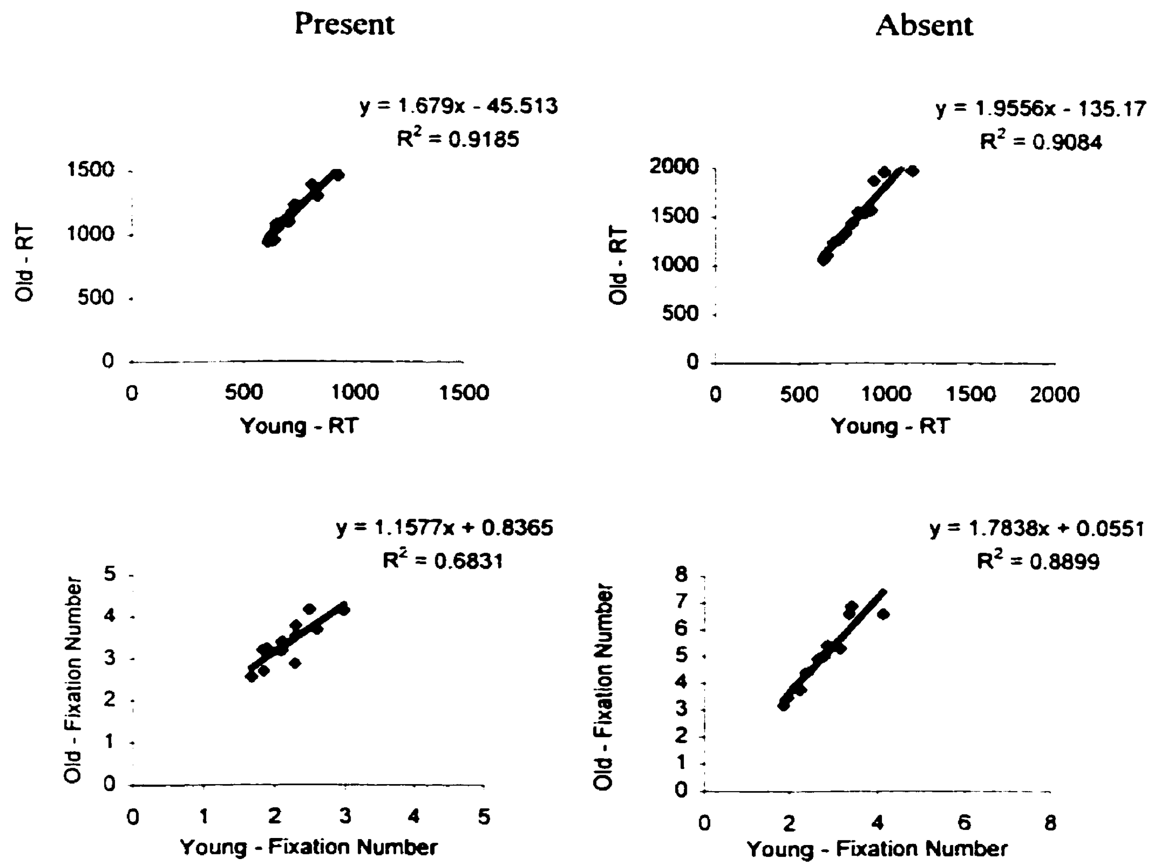


Figure 9. Brinley plots for target-present (left) and target-absent (right) trials Training Period 2. Older adults' RTs (top) and fixation number (bottom) are plotte as a function of younger adults'.

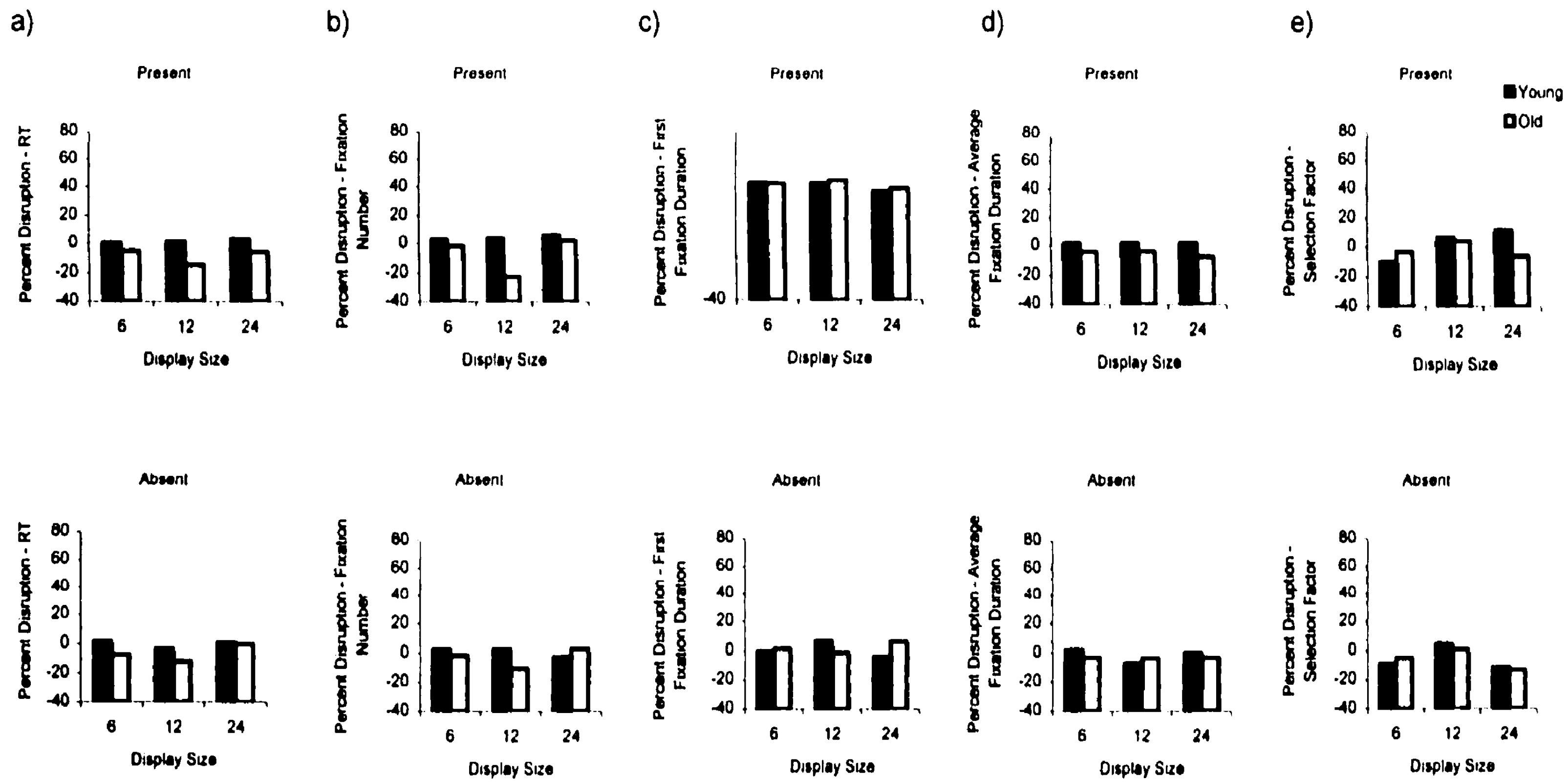


Figure 10. Disruption scores (Session 9 data - Session 8 data/Session 8 data) after the second reversal for target-present (top panel) and target-absent (bottom panel) trials as a function of age and display size. From left to right, the data are for RT, fixation number, first fixation duration, average fixation duration, and the selection factor.

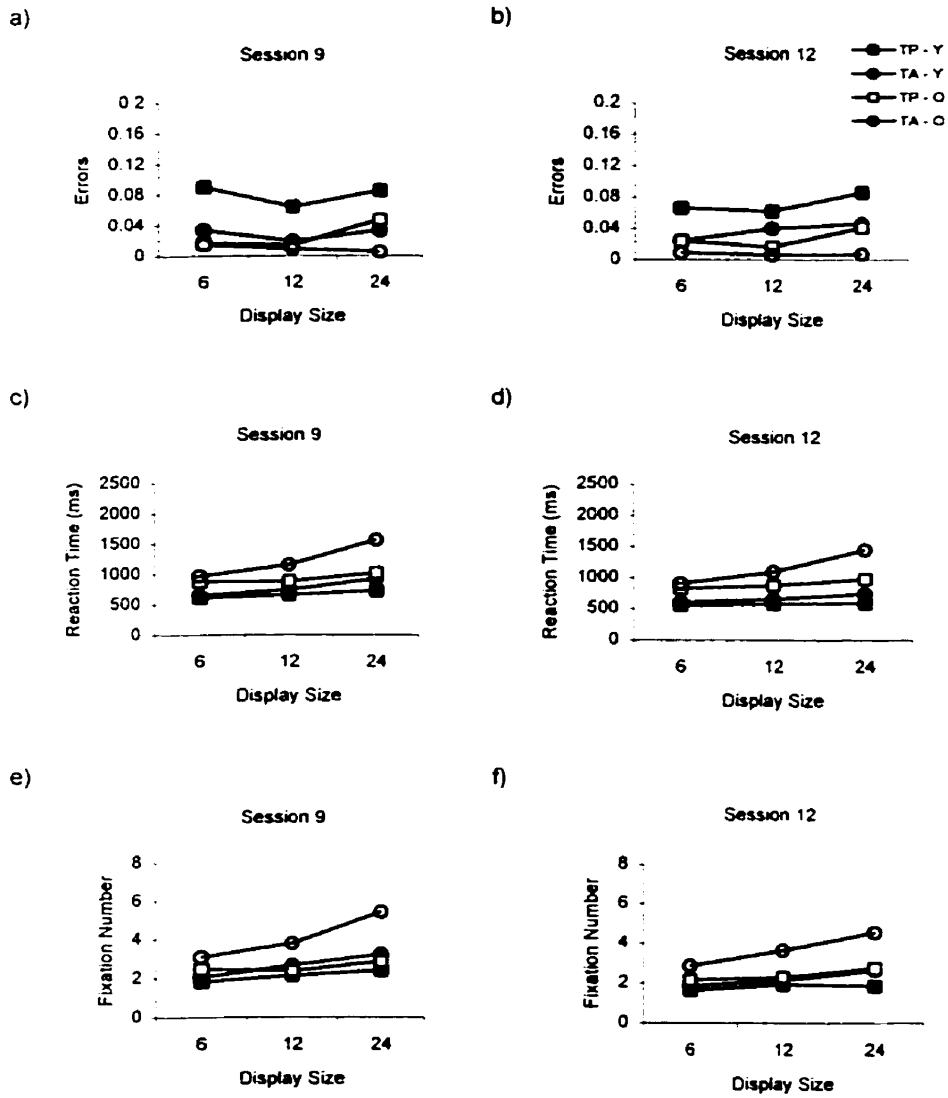


Figure 11. Conjunction search performance in Training Period 3 as a function of age, display size, and target-presence. Left panels, Session 5; Right panels, Session 8. From top to bottom: accuracy, RT, and fixation number.

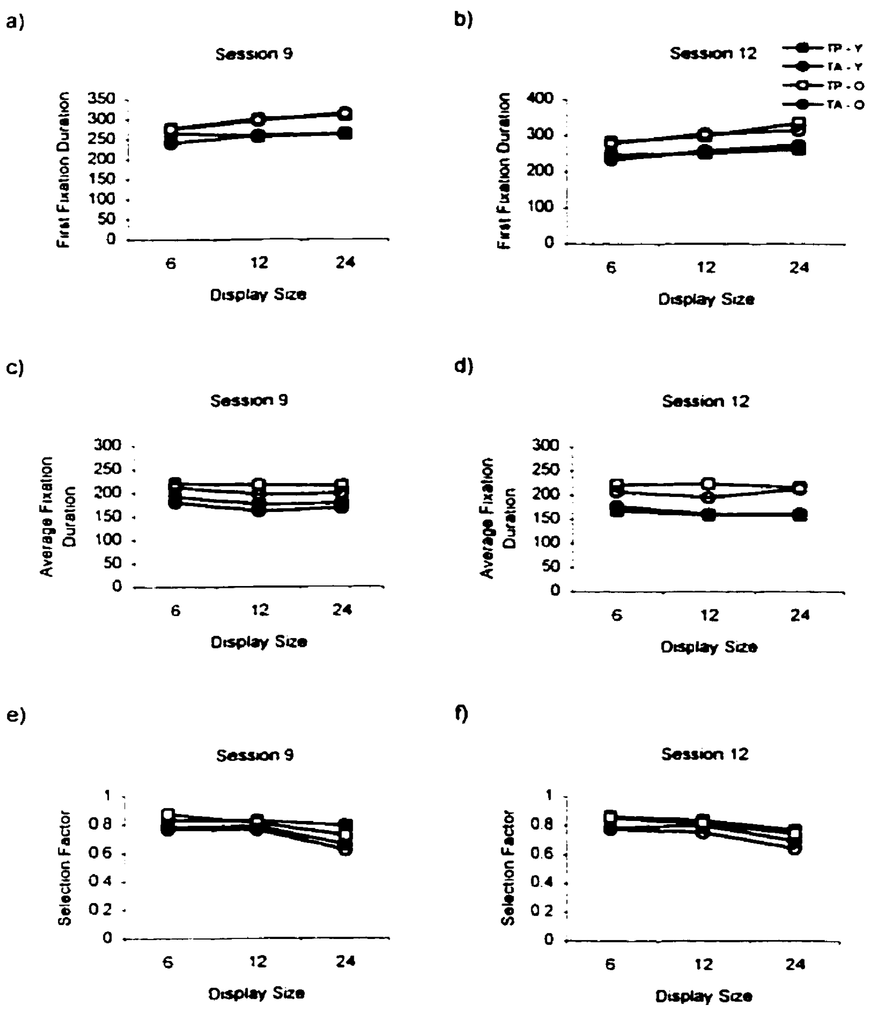


Figure 12. Conjunction search performance in Training Period 3 as a function of age, display size, and target-presence. Left panels, Session 9; Right panels, Session 12. From top to bottom, first fixation duration, average fixation duration, and the selection factor.

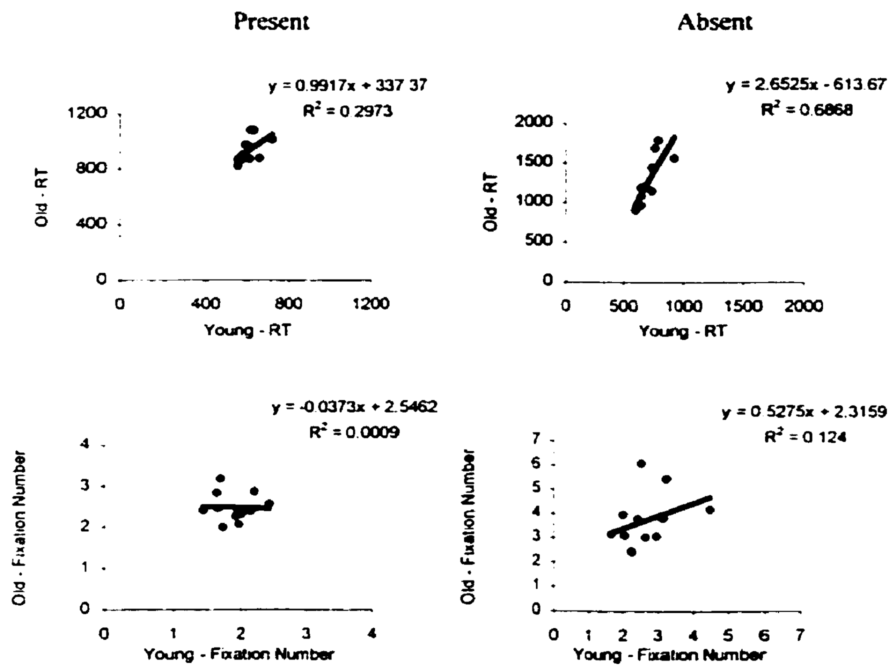


Figure 13. Brinley plots for target-present (left) and target-absent (right) trials Training Period 3. Older adults' RTs (top) and fixation number (bottom) are plotted as a function of younger adults'.

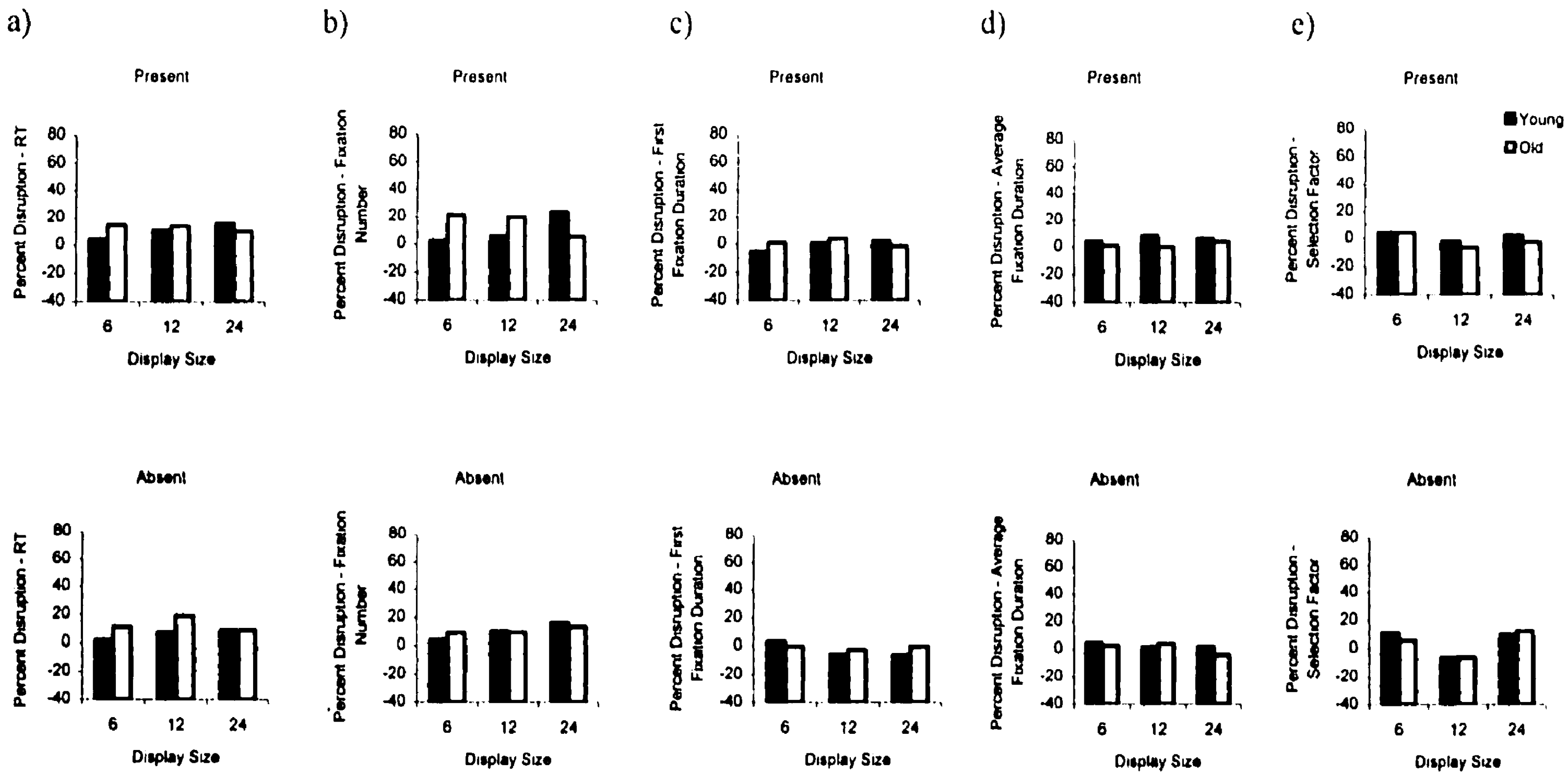


Figure 14. Disruption scores (Session 13 data - Session 12 data/Session 12 data) after the third reversal for target-present (top panel) and target-absent (bottom panel) trials as a function of age and display size. From left to right, the data are for RT, fixation number, first fixation duration, average fixation duration, and the selection factor.

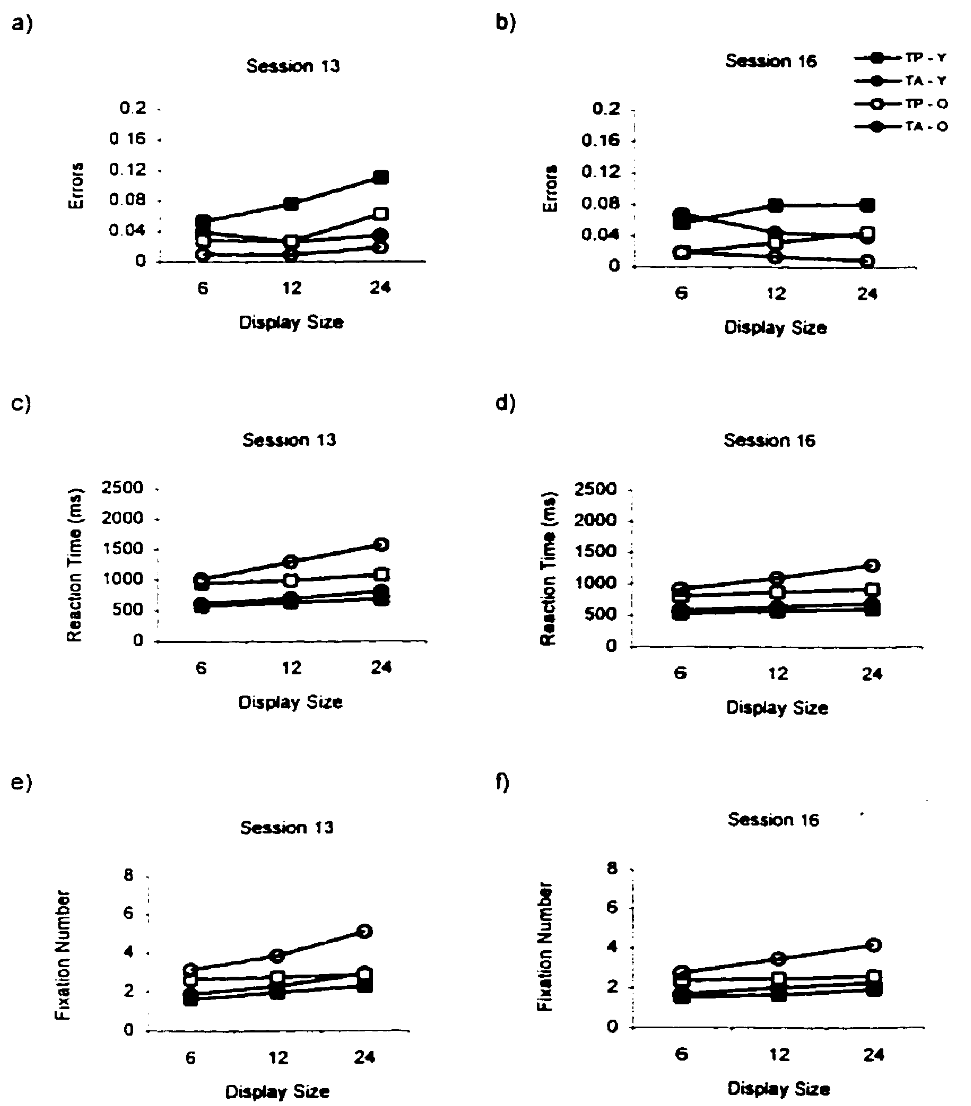


Figure 15. Conjunction search performance in Training Period 4 as a function of age, display size, and target-presence. Left panels, Session 13; Right panels, Session 16. From top to bottom: accuracy, RT, and fixation number.

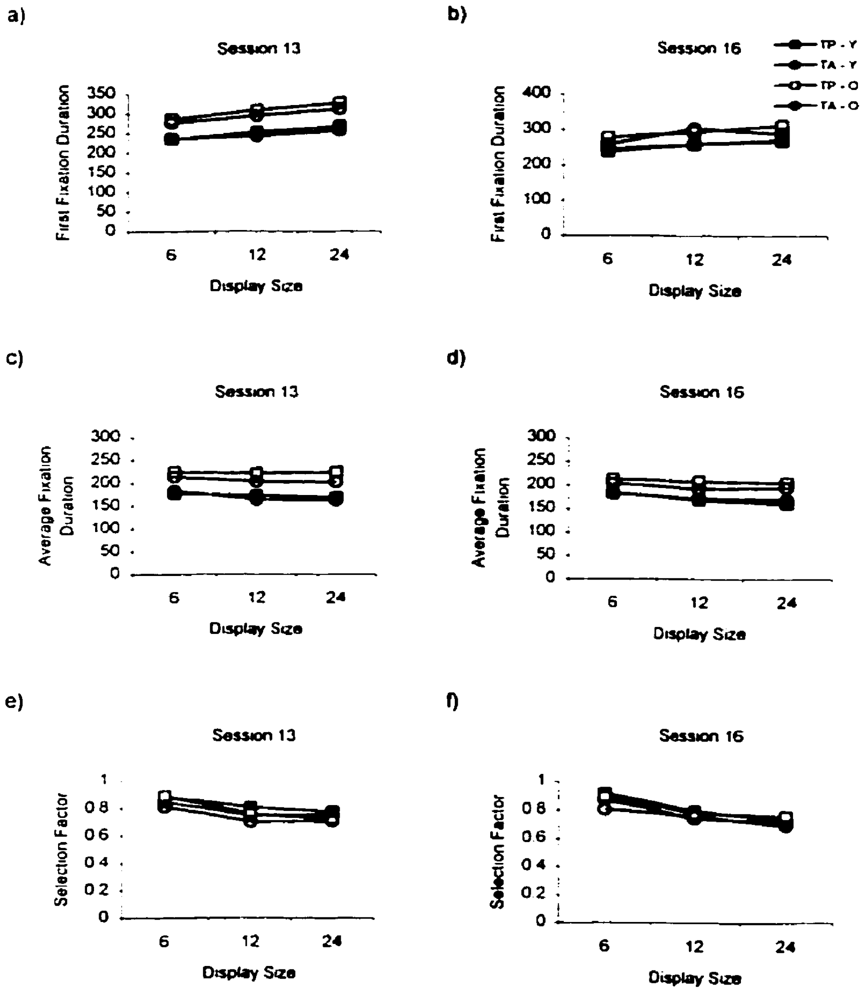


Figure 16. Conjunction search performance in Training Period 4 as a function of age, display size, and target-presence. Left panels, Session 13; Right panels, Session 16. From top to bottom: first fixation duration, average fixation duration, and the selection factor.

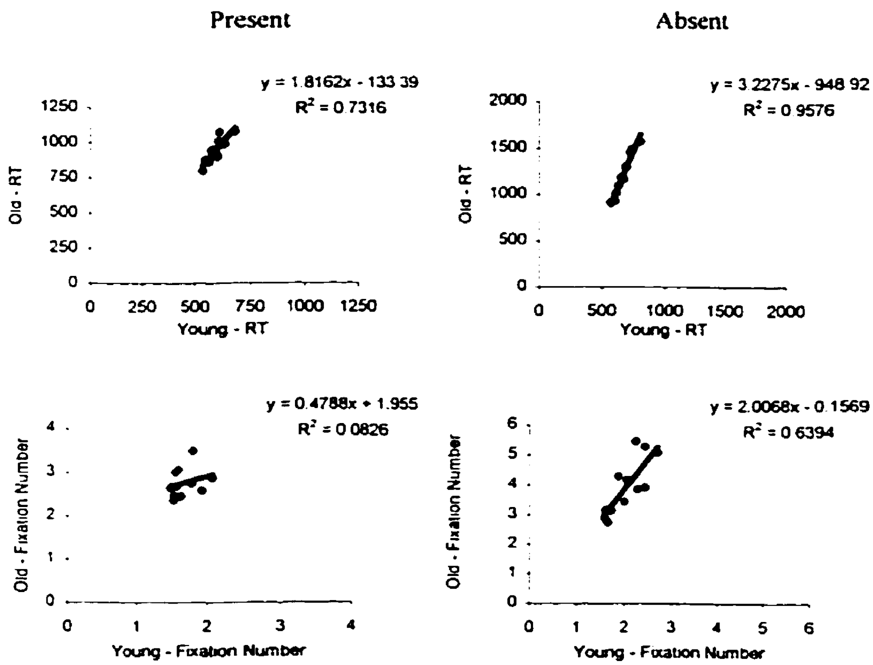


Figure 17. Brinley plots for target-present (left) and target-absent (right) trials Training Period 4. Older adults' RTs (top) and fixation number (bottom) are plotted as a function of younger adults'.

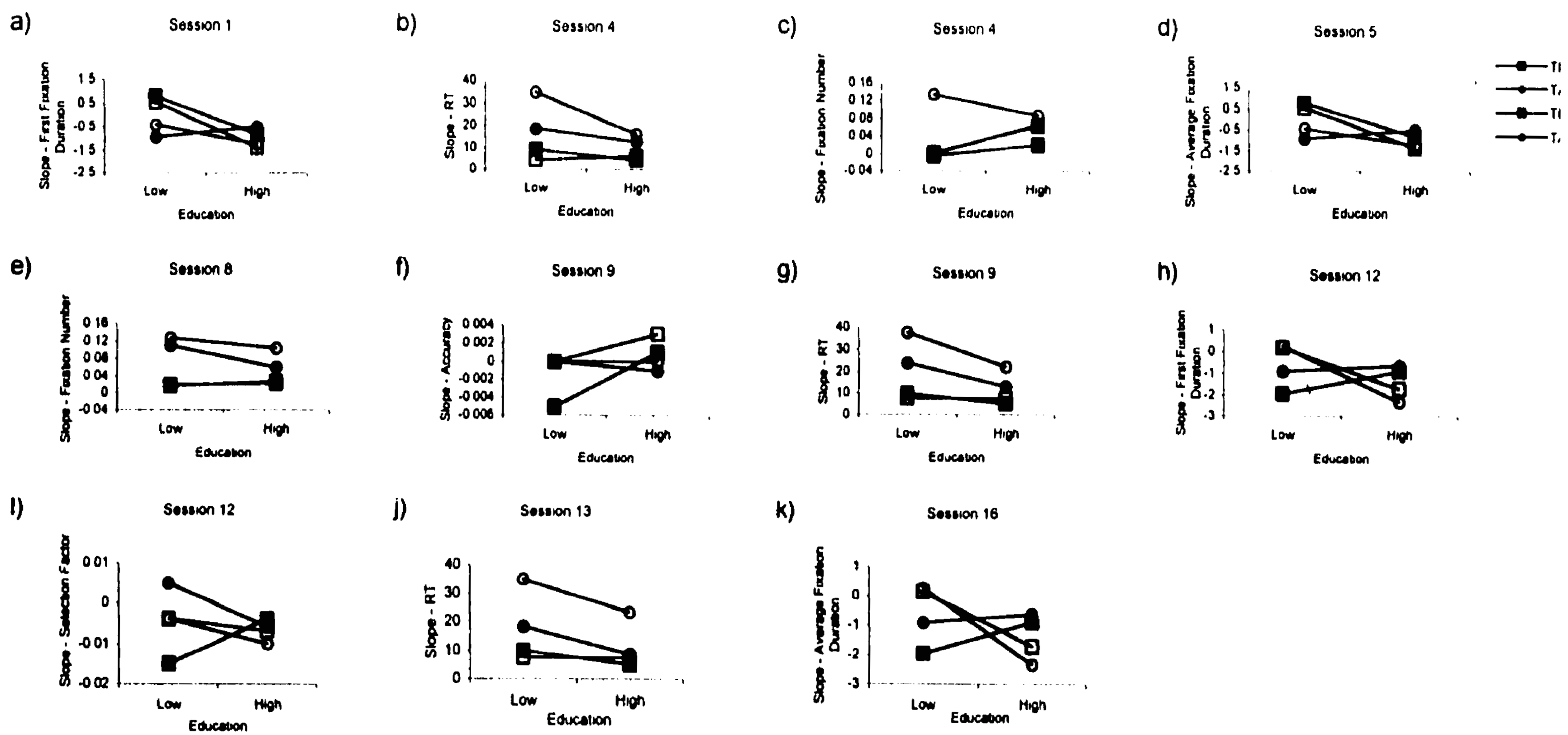


Figure 18. Display size slopes as a function of education for dependent measures containing significant effects of education.

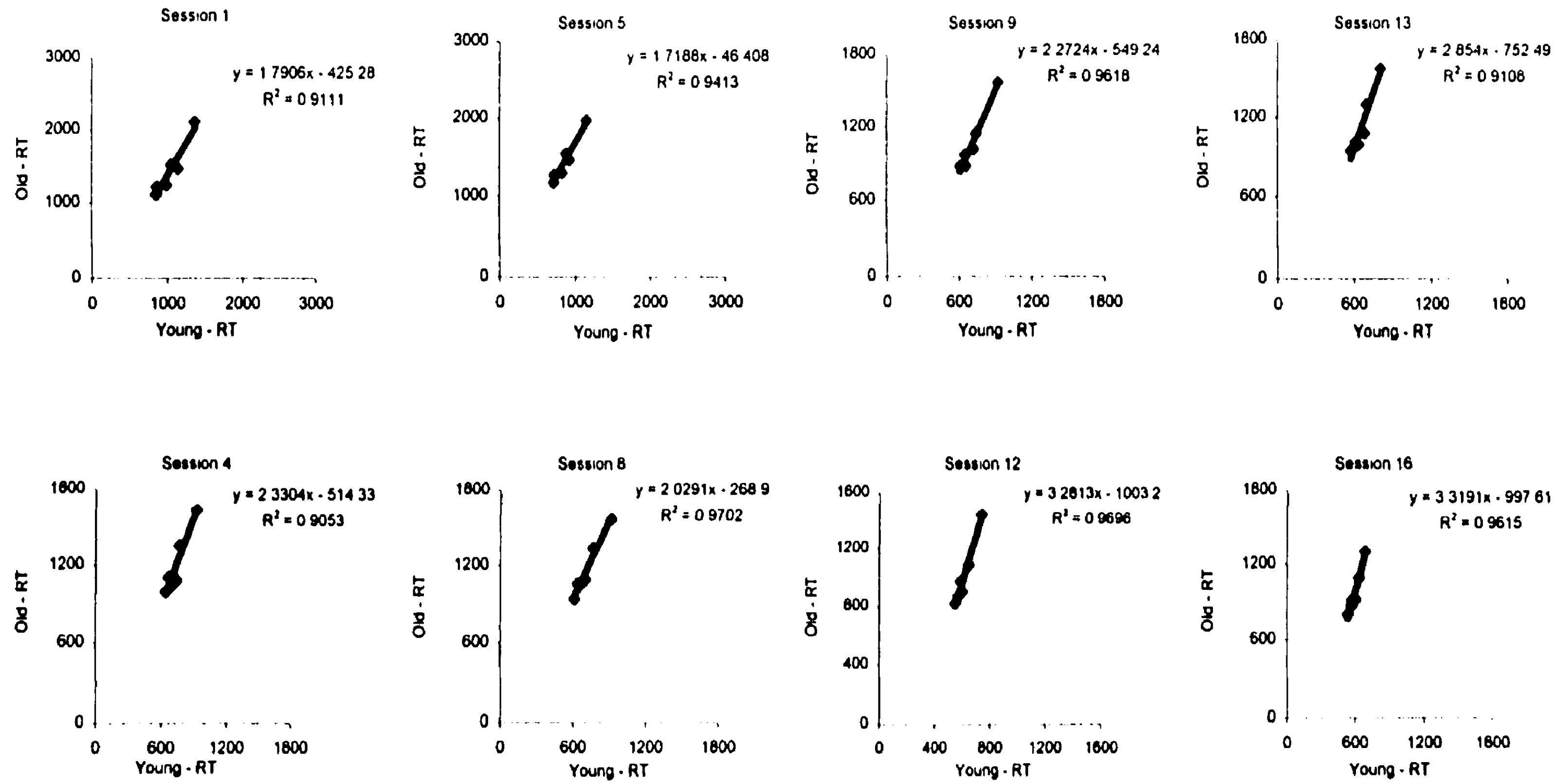
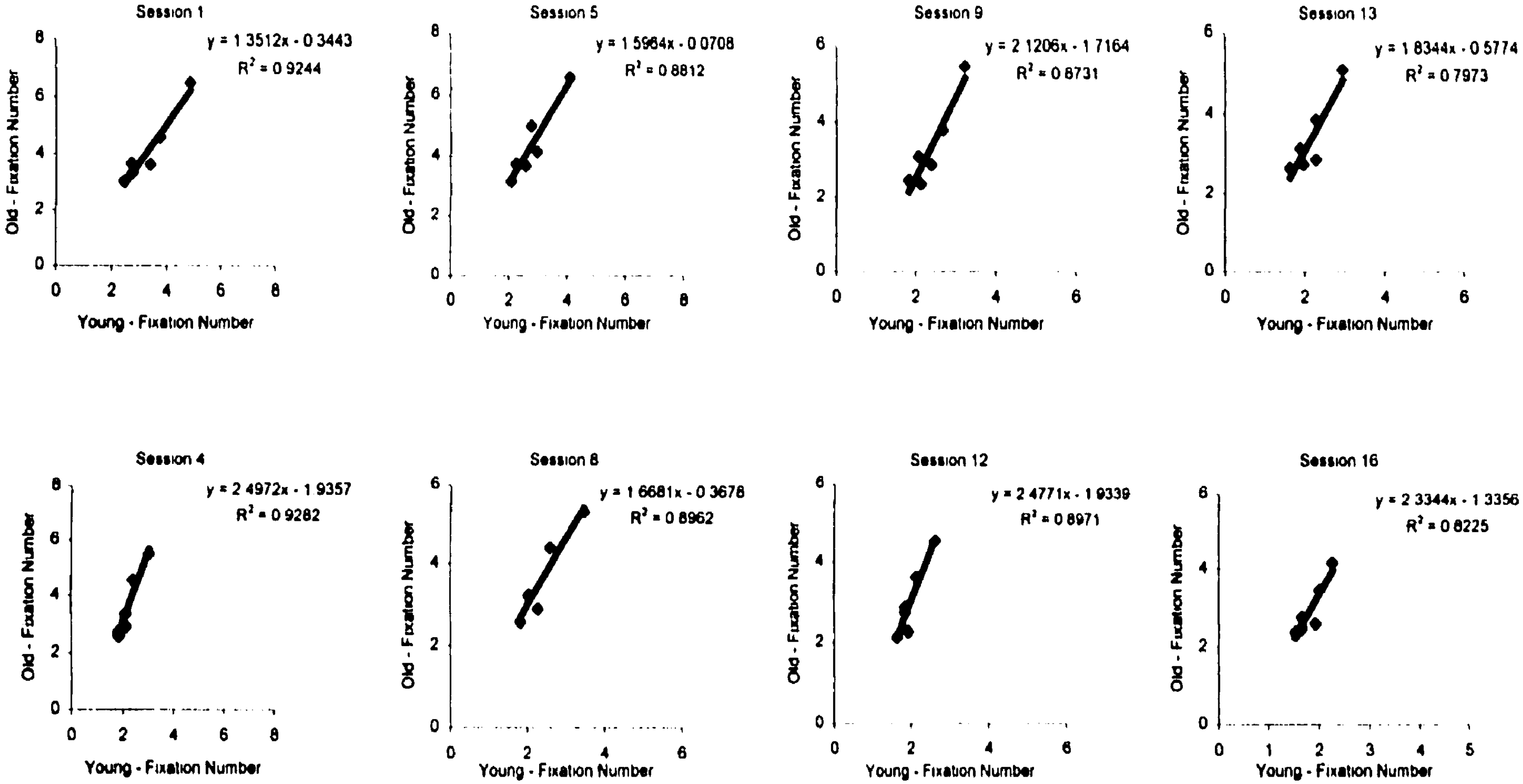


Figure 19. Brinley plots for RT for the first session of each training period (top) and last session of each training period (bottom). Older adults' RTs are plotted as a function of younger adults'.



<u>Figure 20.</u> Brinley plots for fixation number for the first session of each training period (top) and last session of each training period (bottom). Older adults' fixation numbers are plotted as a function of younger adults'.