ASSESSING SPATIAL ATTENTION IN HEALTHY YOUNGER AND OLDER ADULTS

by

JACQUELINE J. LOBOSCO

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Nancy S. Foldi, Ph.D.

Date

Chair of Examining Committee

Joseph Glick, Ph.D.

Date

Executive Officer

Nancy S. Foldi, Ph.D.

Jeffrey M. Halperin, Ph.D.

Alan Kluger, Ph.D.

Andrea Li, Ph.D.

S. Deborah Majerovitz, Ph.D.
Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

by

Jacqueline J. LoBosco

Adviser: Professor Nancy S. Foldi

Background: This study explored late life effects on attention. We assessed attentional capacity in a simple reaction time task (SRT), emphasizing the psychological refractory period (PRP), and covert orienting in two endogenous detection tasks, a traditional symbolic (symbolic COVAT) and a ‘semantic’ orienting task (semantic COVAT). **Method**: Healthy participants (young, 20-39 yrs; mid-old, 60-79 yrs; old-old, > 80 yrs) were tested. The SRT was administered pre- and post other computer tasks to assess fatigue or practice effects (session: two levels), and presented targets at varied stimulus onset asynchronies (SOA: four levels); PRP was expected after the shortest SOA. The endogenous orienting tasks measured validity effects (invalid RT–valid RT), RT costs (invalid RT–neutral RT), and RT benefits (neutral RT–valid RT) with centrally presented valid, neutral, or invalid cues: arrows in the symbolic COVAT, and names of animate and inanimate items in the semantic COVAT. Performance on cognitive domains scores of speed, standard attention, memory, visuospatial, and executive functioning were used as correlates. **Results**: All tasks revealed faster overall speed in the young group than older groups, with no differences between mid-old and old-old groups. PRP effect was enhanced in the old-old group on repeated administration. Correlations demonstrated that the young and mid-old group used different strategies (Attention R= –.69 and Speed R=–.66, respectively) to respond at equivalent rates. When they used similar strategies

(Speed R= -.653 & -.841), the mid-old group performed at a significantly slower rate. On symbolic orienting, the oldest group's significant validity effect, *F(3,122)=3.07, p=.02,* was due to greater benefits (p=.03) not costs (p=.37). The validity effect was not significant in the semantic COVAT. **Conclusions**: Load and fatigue tax late-life attentional capacity, highlighted by enhanced PRP on the SRT. The mid-old group drew on attentional resources to match the speed of young on the SRT. Covert orienting findings of the oldest group showed that they may treat neutral like invalid cues, and/or rely preferentially on valid, predictive cues. Semantic categories did not guide spatial attention.

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Introduction

The well-documented, limited capacity theory (Kahneman, 1973) suggests that capacity limitations restrict the amount of information that can be processed at any given time. Attentional mechanisms that allocate available resources are therefore necessary to attend to what is important or relevant. Orienting is one such mechanism. By directing available resources to a circumscribed area in space or aligning attention to a place in the visual field (Posner, 1980), orienting allows for enhanced processing at that site. When the alignment of attention is accompanied by foveation on the point of interest, it is referred to as overt orienting. But, attentional orienting can also occur in the absence of eye gaze to the stimulus, a mechanism referred to as covert orienting (Posner, 1980). These covert shifts of attention can be directed automatically in response to an external event, or in a voluntary manner as the result of intentions of the individual. Voluntary, or “endogenous” orienting, is said to be goal-directed and is influenced by top-down processes (Hopfinger et al., 2000). The current study examines covert endogenous orienting across the lifespan, and explores how one type of top-down process, the use of semantic knowledge, can be used to allocate attention.

Prior research suggests that under certain conditions, aspects of voluntary orienting show age-related decrements. These impairments are typically seen in orienting tasks that require target discrimination (Greenwood et al., 1993; Greenwood & Parasuraman, 1994; Hoyer & Familant, 1987), rather than detection (Folk & Hoyer, 1992; Greenwood et al., 1993; Nissen & Corkin, 1985; Robinson & Kertzman, 1990). Difficulties are sometimes explained by changes to posterior/parietal areas associated specifically with the disengage component of orienting (Greenwood & Parasuraman, 1994) but they may also be associated with frontally mediated functions (Juola et al., 2000; Whelihan & Lesher, 1985). Experimental manipulations of varied duration between cue and target onset (Greenwood et al., 1993; Hoyer & Familant, 1987; Nissen & Corkin, 1985) and different dependent measures of RT analyses [e.g., validity effect (invalid RT – valid RT), versus RT costs (invalid RT – neutral RT) and RT benefits (neutral RT – valid RT)] may also account for some of these inconsistencies. Thus, effects of age on covert orienting are still unresolved. Furthermore, research on individuals in very late life is limited, leaving open the question of whether there are qualitative changes in the very old on aspects of orienting. This thesis addresses these limitations by expanding the age groups to include individuals in very late life and analyzes the validity effect, as well as separate RT costs and RT benefits in the traditional symbolic orienting task.

Cognitive theories of aging may provide a framework for understanding age-related declines in orienting. Theories of aging include overall slowing (Cerella, 1985; Salthouse, 1985), selective vulnerability of frontal regions (Pugh & Lipsitz, 2002; Raz et al., 1997; Tisserand et al., 2002), and/or recruitment and compensation of different cortical areas while performing cognitive tasks (Cabeza, 2002; Grady, 2000). This study investigates theories of slowing and frontal decline via neuropsychological measures and evaluates their possible contributions in tasks of covert orienting. The possibility of recruitment of alternate neural strategies to perform experimental tasks in the older groups is also raised via correlations between performances on neuropsychological measures and experimental tasks.

Although some cognitive functions, particularly those associated with fluid intelligence, are vulnerable to the effects of aging (Horn, 1982; Horn & Cattell, 1966), others, particularly those associated with crystallized intelligence, are more resilient (Horn, 1982; Horn & Cattell, 1967). Semantic knowledge, which is part of crystallized intelligence, remains relatively preserved in the elderly (Burke & Peters, 1986; Horn & Cattell, 1967; Mayr & Kliegl, 2000). Although some studies document decline in some aspects of semantic knowledge (Allen et al., 1993; Bäckman & Nilsson, 1996; Bowles & Poon, 1985; Craik & Simon, 1980), there is support for preservation of vocabulary knowledge (Verhaeghen, 2003) and semantic categorization (Yoon et al., 2004), components important for the current study.

The connection between semantic knowledge and covert orienting was introduced in a previous covert orienting study (Lambert & Sumich, 1996). Results suggested that semantic information, specifically categories of words, rather than symbolic information such as arrows, can be used to influence spatial orienting. In the study, peripherally presented cue words predicted subsequent target location with 80% accuracy. The learned association between semantic category and target location was demonstrated by faster RT to targets appearing in expected than unexpected locations. This raises the possibility that involvement of preserved semantic functions could facilitate tasks that otherwise may be declining with age. That is, spared semantic skills may be used as a directed way to allocate attentional resources.

In sum, there appears to be an age-related decline in covert orienting, most prominently in voluntary orienting. However, to our knowledge, only one study to date has investigated covert orienting in individuals over the age of 80. This study addresses this paucity of information in the literature by examining individuals over the age of 80 on aspects of voluntary orienting. We administered three attention tasks, a simple reaction time, a symbolic orienting, and a semantic orienting task to three groups of healthy young, mid-old, and old-old individuals. Converging data from standard neuropsychological tests in the domains of executive function, as well as attention, language, memory, speed and visuospatial functions are examined for possible relationships to voluntary orienting mechanisms.

Orienting of attention

Orienting task

Cued orienting has been long established in the literature as an important component of attention (Bashinski & Bacharach, 1980; Jonides, 1981; Posner, 1980). In the prototypical covert orienting task, arrows presented centrally generate expectancies about the subsequent target location. Arrows that accurately predict target location, referred to as valid cues, promote faster detection speed than cues that do not predict target location (neutral cues) or those that inaccurately predict target location (invalid cues). Using reaction time (RT) as a measure of detection speed, the facilitory effect of valid cueing is inferred from shorter RT latencies to valid than neutral trials, referred to as "RT benefits" and cost of invalid cueing from longer RT latencies to invalid than to neutral trials, referred to as "RT costs" (Posner, 1980). "Combined RT costs and benefits" (invalid RT - valid RT) or the "validity effect" can also be used as a measure of efficacy of cued orienting.

Orienting may be enhanced by presenting a higher proportion of valid than invalid cues. In a series of experiments, Jonides (1980) demonstrated that higher probabilities of valid than invalid trials resulted in greater magnitude of costs and benefits, or a greater validity effect. Traditional orienting tasks (Wainwright & Bryson, 2005; Warner et al., 1990; Yantis & Jonides, 1990) use an 80/20 contingency with valid cues occurring on 80% of the trials and invalid cues on 20% of the trials. To maximize the development of expectancies in the current study, an 80/20 contingency between cues and target locations is used.

Neurobiology subserving orienting

Neurobiological models of attention implicate the posterior parietal system in orienting (Fan et al., 2005; Posner & Petersen, 1990); however, there also appears to be frontal system mediation, particularly in aspects of voluntary orienting (Corbetta & Shulman, 2002; Kim et al., 1999). According to Posner (Fan et al., 2005; Posner & Petersen, 1990), orienting is one of three independent yet interconnected attention systems, which also include alerting, and detection or “executive control” (Fan et al., 2005). The orienting response activates a neural network that guides attention to a circumscribed area in space. Discrete functions of this system include disengagement, shifting, and engagement mediated by parietal areas (Posner et al., 1984; Posner et al., 1987), the superior colliculus (Sprague, 1991), and the pulvinar of the thalamus (LaBerge, 1997) respectively. This network was traditionally associated with the posterior attention system thought to operate independently from the anterior attention system responsible for the detection of signals (Posner & Petersen, 1990) and conflict resolution (Fan et al., 2002), as well as the vigilance system of the brain, typically associated with thalamic, frontal and parietal regions, and strongly lateralized to the right hemisphere (Fan et al., 2005). While independent of the alerting and detecting systems, the orienting network is strongly connected with the other two attentional networks. For example, using functional magnetic resonance imaging (fMRI) Fan and colleagues

(2005) found activation of common brain areas during orienting and conflict tasks (left BA 6 and bilateral BA 37) as well as during orienting and alerting tasks (BA 7) offering support for the interaction of these attention systems. A key component of these models is the focus on localization of function that provides researchers with critical information about the fundamental components of a very complex system. With anatomy and function of aspects of orienting isolated, the ability to identify the possible etiology of decline is enhanced. In the current study, we hope to correlate aspects of endogenous orienting with cognitive functions of neuropsychological tasks known to represent neuroanatomical systems.

Mesulam's model of attention (Kim et al., 1999; Nobre et al., 1997; Nobre et al., 2004) views the attention network more holistically, as a widely distributed system that activates supplementary cortical regions, including the dorsolateral prefrontal cortex. Whereas some researchers (Fan et al., 2005; Posner & Petersen, 1990) parse out target detection as a separate function mediated by the executive control network, Mesulam and colleagues (Kim et al., 1999) consider this function to be part of the orienting system. Support for involvement of additional neural substrates is derived from imaging studies. For example, using fMRI in tasks of exogenous and endogenous orienting (Kim et al., 1999), activations were observed in expected anatomical regions (posterior parietal cortex, putamen, frontal eye fields, cingulate gyrus, and the thalamus), as well as additional brain areas (anterior insula, dorsolateral prefrontal cortex, temporo-occipital cortex, supplementary motor area, and the cerebellum). Involvement of the frontal system in orienting raises the question of whether age-related decline in orienting can be attributed to changes in the anterior versus the posterior system as previously believed (Posner & Petersen, 1990).

Frontal system involvement is also posited in Corbetta and Shulman's dual model of attention (Corbetta & Shulman, 2002). In this model, the attention system consists of "partially segregated" networks, one responsible for bottom-up detection of behaviorally relevant information and the other specialized for goal-directed selection of stimuli. Using fMRI to isolate brain areas involved in stimulus-driven attention, Corbetta and Shulman (2002) found activations in the temporo-parietal junction and ventral frontal cortex, strongly lateralized to the right hemisphere. They proposed that the ventral fronto-parietal network represents the exogenous orienting system that directs spatial attention to salient stimuli (Corbetta & Shulman, 2002; Kincade et al., 2005). On the other hand, bilateral activations in the posterior parietal, as well as the frontal cortex are associated with top-down orienting, linked specifically to endogenous aspects of orienting. This "dorsal frontoparietal network" is responsible for the control of visuospatial attention, stimulus processing, and the preparation of eye and arm movements. Furthermore, Hopfinger and colleagues (2000; 2001) investigate voluntary orienting in response to instructive cues and link lateral and medial superior frontal lobes or the dorsolateral prefrontal cortex with top-down attentional processes. Neuroanatomical evidence from all three models implicates frontal brain regions in voluntary orienting. In this study, relationships between frontally-mediated behavioral tasks and endogenous orienting tasks are examined to better understand the role of frontal systems in spatial orienting.

Exogenous versus endogenous orienting

There are two mechanisms underlying shifts in spatial attention on cued orienting tasks. The exogenous orienting mechanism is activated when visual stimuli in extrapersonal space automatically captures attention, and is believed to operate via “bottom-up,” automatic, or involuntary processes (McCormick, 1997). Cues often used in exogenous orienting tasks include the transient appearance of a stimulus (Jonides, 1981; Warner et al., 1990; Yeshurun & Carrasco, 1998) or flash of light (Müller & Rabbitt, 1989; Posner, 1980; Shepherd & Müller, 1989). Valid exogenous cues speed detection of targets presented within 200 ms after cue onset (Cheal & Lyon, 1991; Maruff et al., 1999; Posner & Cohen, 1984; Posner & Petersen, 1990; Shepherd & Müller, 1989), however, if the target is presented more than 200 or 300 ms after cue onset, detection speed decreases, a phenomenon called “inhibition of return” (Berger et al., 2005; Maylor & Hockey, 1985; Posner, 1980; Posner & Cohen, 1984). In endogenous orienting, attention is guided by internal, rather than external events via “top-down” processes (Hopfinger et al., 2000). Endogenous orienting tasks often use centrally presented cues to direct attention, such as an arrow (Jonides, 1981; Posner, 1980), directive words (e.g., ‘right’ or ‘left’: (Hommel et al., 2001), or instructions (e.g., advance verbal information about target location: (Hoyer & Familant, 1987). Facilitation to endogenous cues occurs approximately 300 ms after cue onset and is not subject to inhibition of return (Cheal & Lyon, 1991; Shepherd & Müller, 1989). It is however, influenced by other factors. Jonides (1981) suggested that memory load of a secondary task can reduce the efficiency of cueing to endogenous cues.

Semantic cues with no inherent spatial meaning have also been posited to guide spatial attention. In two exogenously cued orienting tasks, Lambert and Sumich (1996) used words from semantic categories (animate and inanimate) as central cues; an 80/20 contingency between cue word category and target location was used to promote expected location of the target (e.g., if an animate cue word was presented, the target was likely to appear – with an 80% chance – on the opposite side). Participants were not informed of this relationship between cue category and target location and were instructed to detect targets as quickly as possible. Participants responded with faster RT to targets occurring in likely locations than in unlikely locations, demonstrating that they learned the implicit relationship between semantic category and target location. Despite evidence of the facilitory effects of semantic cues, participants were not able to articulate the relationship between cues and targets confirming the implicit nature of these tasks. In another experiment (Lambert & Sumich, 1996), cue words were again presented to the right and left of fixation but targets appeared above and below fixation to avoid spatial overlap. Again, contingencies between cue word category and target location were 80/20. Findings from this task were: 1. RT was faster to targets appearing in likely than unlikely locations, 2. expectancies were developed and participants were able to articulate the learned cue-target association at greater than chance level, and 3. expectancies drove performance in this task such that RT was faster at consciously expected locations than likely locations. In the proposed study, we are interested in determining whether individuals are able to use semantic information to predict spatial location when attention is directed in a voluntary manner using centrally, rather than peripherally presented cues.

Aging

Speed hypothesis

Age-related cognitive decline is often associated with slower speed of processing (Cerella, 1985; Hale et al., 1991; Salthouse, 1980; Salthouse, 1991; Salthouse et al., 1996; Salthouse, 1996; Salthouse & Meinz, 1995; Salthouse & Somberg, 1982). A generalized slowing model purports that slowed transmission throughout the central nervous system (Birren et al., 1979; Botwinick, 1984) is the common factor responsible for age-related decline of cognitive operations. Level of impairment on cognitive functions in late life can be determined by measuring RT latency of young individuals on the same task and is approximated by a linear regression line or Brinley function. General slowing is also used to account for the poorer performance of older than younger adults on more demanding and complex tasks, a phenomenon referred to as the "age-complexity" phenomenon (Salthouse, 1992). Salthouse suggests that reductions in speed required to execute fundamental operations contribute to impairments in working memory. Because challenging tasks place high demands on working memory, the decrement in speed at the basic level of simple operations is largely responsible for the difficulties experienced by the older individuals on these more complex cognitive tasks.

Findings of Lima and colleagues (1991) suggest that age-related slowing occurs at different rates for lexical and non-lexical tasks. To evaluate the effects of slowing in lexical and non-lexical domains, they examined—in three separate meta-analyses—the developmental trends of processing speed from 19 studies. They examined speed of processing within the lexical domain using lexical decision tasks (LDT: Analysis 1), lexical tasks other than LDT (Analysis 2) and nonlexical tasks (Analysis 3). The first two meta-analyses of lexical processing tasks revealed a similar linear relationship between the latencies of younger and older individuals. However, in the nonlexical meta-analysis, although they found a linear relationship between younger and older latencies, the relationship did not match that of the lexical domain. Results suggested greater slowing in the nonlexical domain. These findings suggest that age-related speed changes may be domain-specific, and does not affect all cognitive domains equally.

Frontal Aging Hypothesis

Examining the integrity of frontal regions of the older brain has been the focus of a great number of studies (Bryan & Luszcz, 2000; Dempster, 1992; Fuster, 2000; Stuss et al., 1995; Stuss et al., 1999; Whelihan & Lesher, 1985). Evidence of selective vulnerability of the frontal regions and relative sparing of frontal-independent cortical areas of the brain is presumed to account for many age-related cognitive changes. We were particularly interested in this area of research to determine if frontal system changes effect voluntary aspects of covert orienting.

Neurobiological support for the frontal aging hypothesis is derived from studies that demonstrate reductions in brain volume of gray matter within specific regions of the frontal (Tisserand et al., 2002), and prefrontal cortex (Raz et al., 1997), in white matter (Jernigan et al., 2001; Raz et al., 1997) in regional cerebral blood flow (Gur et al., 1987), and in synaptic density over the age of 74 (Huttenlocher, 1979). Behavioral support for specific frontal vulnerability comes from studies demonstrating decline on neuropsychological measures tapping cognitive functions associated with frontal regions, such as inhibition (Hasher & Zacks, 1979), working memory (McEvoy et al., 2001) context memory (Cabeza et al., 1997; Craik et al., 1990), memory loss for temporal order

(Parkin et al., 1995), and tasks of recognition and subjective organization (Parkin et al., 1995).

However, the frontal aging hypothesis has not received universal support. Greenwood (2000) argues that frontal-dependent declines are accompanied by “frontal-independent” cognitive declines, compromising the premise of selective impairment of executive functions. Furthermore, decreased volume and metabolism in non-frontal regions in the older brain, such as the temporal lobes (Golomb et al., 1994) have also been documented, further undermining an exclusive frontal regional decline. Additionally, Greenwood (2000) highlighted methodological flaws of several studies leaving interpretations based on their findings suspect. For example, although Dempster (1992) demonstrated age-related frontal volume loss, no comparisons to other brain areas were made, leaving open the question of whether volume loss is specific to the frontal lobe. And while West (1996) documented that there is an age-related increase in number of senile plaques in the frontal regions of the healthy brain, he acknowledged that the functional significance of their presence is not known. That is, the count of plaques may not necessarily correlate with decline in cognitive abilities. So, while most researchers may not dispute the existence of frontal decline in later life, some questions remain as to whether the frontal aging hypothesis adequately accounts for all aspects of age-related decline. For purposes of the current study, the frontal aging hypothesis is being addressed in terms of the relationship between executive control vulnerability in late life and voluntary orienting. Standard neuropsychological measures associated with frontal functions, as well as non-frontal functions, including attention, language, memory, speed, and visuospatial tasks are administered. It is predicted that behavioral measures in multiple neuropsychological domains, not only those associated with executive control, correlate with attentional measures of the covert orienting tasks.

Hemispheric Asymmetry Reduction in Old Adults model

Early notions of hemispheric asymmetry had been posited, with greater age-related decline in the right than left hemisphere (Klisz, 1978). More recently, Cabeza and others (Cabeza et al., 1997; Cabeza et al., 2002; Cabeza, 2002; Reuter-Lorenz et al., 1999) introduced the model of hemispheric asymmetry reduction in old adults (HAROLD) as an explanation for brain-related changes in late life. Functional neuroimaging studies reveal changes in the organization of neuroanatomical connections, typically including reduced lateralization in frontal regions of the brain, during performance of certain cognitive tasks (Cabeza et al., 1997; Cabeza et al., 2002; Madden et al., 1999; Reuter-Lorenz et al., 1999). Increased bilateral frontal activity during retrieval tasks in older than younger adults as documented in several PET studies (Cabeza et al., 1997; Madden et al., 1999) comparing regional cerebral blood flow (rCBF) can be interpreted as being due to functional compensation for age-related decline. That is, recruitment of additional brain regions is necessary for the execution of tasks that typically rely on fewer neuroanatomical areas in younger adults. Consistent with the compensatory theory of the HAROLD model is another PET study (Reuter-Lorenz et al., 2000) that correlates increased bilateral prefrontal activity with faster performance on a working memory task. As further evidence for a compensatory role of the HAROLD model, Cabeza cites several studies (see (Cabeza, 2001) that demonstrate that the recruitment of additional brain regions following unilateral brain damage facilitates recovery of function.

An alternative interpretation for the age-related asymmetry reduction in older individuals is explained by the “age-related dedifferentiation hypothesis” (Cabeza, 2001). This theory posits that the recruitment of additional neural regions in later life is secondary to difficulties of older individuals in recruiting the specialized neural mechanisms that are available to younger individuals. Evidence definitively supporting one theory over the other is not yet available; however, there is strong evidence for task-related changes in dependence on additional brain regions with increasing age. The relationship between age-related reorganization of cortical connections and tasks of covert orienting has not yet been established in the literature and is beyond the scope of this study. However, an awareness that neural connections may be altered in late life and serve a compensatory role should be acknowledged and considered in future studies investigating declines in voluntary spatial orienting.

Aging and covert orienting

The effects of age are not readily apparent on involuntary orienting (Folk & Hoyer, 1992; Hartley et al., 1990), but are more notable in voluntary components of covert orienting (Greenwood et al., 1993; Greenwood & Parasuraman, 1994). In stimulus-driven, exogenously cued detection tasks, performance of older adults does not differ significantly from that of younger adults (Folk & Hoyer, 1992; Greenwood et al., 1993). Even with more difficult discrimination tasks (i.e., higher load) using peripheral cues, effects of age on the shifting of attention were not found (Greenwood et al., 1993; Hartley et al., 1990). These results point to the relative resilience of the automatic attention system of the brain in later life. However, these studies only assessed individuals up to the age of 79, leaving open the question of whether there are developmental changes in the 9th and 10th decades of life. Results of one exogenous orienting experiment using a discrimination task with individuals up to the age of 84 (Greenwood & Parasuraman, 1994) revealed significantly larger RT costs for the oldest group (ages 75-84) when compared to the next oldest group (ages 65-74). The selective impairment of invalid cueing (increased RT costs), but not of valid cueing (equivalent RT benefits) was interpreted as support for an age-related ‘disengage deficit.’ However, this is the only study conducted with individuals over the age of 80; therefore, additional research with this population should be conducted to confirm the findings.

Some endogenous tasks are also resilient to age-related decline. Performance on detection tasks using endogenous (central) cues do not typically reveal age-related differences (Gottlob & Madden, 1999; Greenwood et al., 1993; Nissen & Corkin, 1985). However, interpretations based on the findings must be made with caution. For example, although Nissen and Corkin (1985) found only a non-significant trend for the validity effect between age groups, they used stimulus onset asynchronies (SOAs) of 2000 and 3000 ms, which is well beyond a saccade and represents overt orienting. Later research finds that peak facilitory effects of endogenous cues occur in the range of 200 to 400 ms (Shepherd & Müller, 1989). Therefore, endogenous detection tasks may show age-related decline when the SOA is shorter.

More difficult choice RT tasks involving voluntary orienting show clear age-related changes. For example, Greenwood and colleagues (1993) administered a letter discrimination task requiring participants to indicate whether the letter target that followed a spatially valid, invalid, or neutral cue was a vowel or a consonant by pressing one of two buttons. Validity effect (invalid RT – valid RT), as well as separate RT costs (invalid RT – neutral RT) and RT benefits (neutral RT – valid RT) were examined to evaluate facilitation of valid cueing and costs of invalid cueing separately. Greater validity effect, but not separate RT costs or benefits, were found for older than younger individuals at SOAs greater than 200 ms. Because separate costs were not significantly affected by age, results are not suggestive of a selective age-related vulnerability of the disengagement process. Similarly, in another letter-discrimination task (Greenwood & Parasuraman, 1994) with individuals up to age 84, the validity effect increased significantly with each decade. In addition, the oldest group exhibited significantly greater costs (but not benefits) than the group 10 years younger, suggesting a selective decline in the efficiency of the disengage process in individuals over the age of 75. Lack of significant differences in RT costs among all other age groups suggest that this disengagement deficit might emerge only in very late life, representing a qualitative change not previously observed in the literature. Given the increased life expectancy of individuals and need for comparison groups for aged individuals with pathological changes, additional research on this oldest cohort is warranted.

Despite evidence for a decline in discrimination tasks, results from additional studies of endogenously cued discrimination tasks are more equivocal. For example, on an endogenously cued character discrimination task (Hartley et al., 1990), the validity effect was greater for older adults than younger adults, both absolutely (invalid RT – valid RT) and relatively [(invalid RT – valid RT)/valid RT]. These results were interpreted by Hartley and colleagues (1990) as evidence that older adults shift attentional resources more efficiently, or at least as efficiently, than younger adults. Interpretations of these findings were based on a priori hypotheses that predicted a greater absolute validity effect in older adults based on age-related slowing and an equivalent relative validity effect if older and younger adults allocated attention to valid and invalid cues in a similar manner. The finding of greater relative combined costs and benefits indicated equivalent or better allocation of attentional resources. Although neutral cues were presented in this study, separate RT costs and benefits were not analyzed, therefore, the source of the greater validity effect (due to facilitation of the valid cues or cost of the invalid cue) cannot be determined. In another series of endogenous discrimination tasks by Folk and Hoyer (1992), younger participants showed the expected validity effect to targets following a centrally presented arrowhead while older participants did not, suggesting that they were unable to benefit from spatial cues. However, when they made the cue easier to discriminate by enlarging the arrowhead and moving it closer to the target location, age differences were reduced and older adults were able to benefit from valid spatial cues similar to young adults. Folk and Hoyer therefore claimed that the elderly do not experience declines in voluntary visuospatial orienting, but rather have difficulties encoding stimuli.

The evidence of poorer performance of older compared to younger individuals in voluntary spatial attention leaves several questions left unanswered. For example, are age-related differences in the validity effect due to dysfunction in the disengage component of orienting (Greenwood & Parasuraman, 1994), due to differences in allocation of attentional resources (Hartley et al., 1990), or simply a function of poor encoding due to visual discrimination (Folk & Hoyer, 1992)? The current study was designed to address issues of late-life changes in voluntary orienting using an endogenous detection task. We include a cohort of individuals over the age of 80 to address the paucity of research on old-old individuals. In addition, we seek to clarify the validity effect and include a neutral condition to see both RT costs and RT benefits separately. If the magnitude of RT costs is greater in the elderly, but RT benefits are equivalent to younger adults, results could be indicative of an age-related disengage deficit or to difficulties with frontal-mediated functions. However, if the magnitude of RT costs and RT benefits is greater for older individuals, this might support the theory of increased allocation of visuospatial attention of older adults as suggested by Hartley et al. (1990). In addition, large, rather than small visual stimuli are used to alleviate potential encoding difficulties of older individuals. Tests of visual acuity and discrimination are conducted to ensure adequate visual abilities of all participants in the experiment. Converging evidence from select neuropsychological tests is examined to better understand relationships between executive, and other cognitive functions with aspects of voluntary orienting.

Semantic knowledge

Preservation of semantic knowledge in late life

Facilitation of performance in older individuals may occur by drawing on preserved cognitive functions. The semantic system is thought to be spared in late life and may serve to benefit declines in spatial orienting. The following summary reviews semantic function in late life.

For many years, it was posited that cognitive functions associated with fluid intelligence (Gf) were vulnerable to the effects of aging (Botwinick, 1984; Horn & Cattell, 1967; Kaufman et al., 1991), while those associated with crystallized intelligence (Gc) were more resilient (Horn & Cattell, 1967; Kaufman et al., 1991), at least up to the age of 74 (Botwinick, 1984). Intact performance on measures of the VIQ (Burke & Peters, 1986; Horn & Cattell, 1967; Lima et al., 1991; Matarazzo, 1972; Schaie, 1994) and tests of vocabulary (Verhaeghen, 2003) were viewed as support for preservation of the semantic system. However, a more systematic exploration of age-related effects on specific components of the semantic system yielded refinement of that overarching idea. Some researchers argue for relative preservation of semantic memory (Eustache et al., 1998; Mayr & Kliegl, 2000), word associations (Burke & Peters, 1986; Howard, 1980), generation of category items (Howard, 1980), semantic organization skills (Cohen & Faulkner, 1983) (Burke & Peters, 1986) and semantic retrieval when processing single words or sentences (Mayr & Kliegl, 2000). However, age-related deficits within the semantic system have been documented in semantic encoding (Allen et al., 1993; Craik & Simon, 1980) and semantic fluency (Bäckman & Nilsson, 1996). Discrepancies in the findings may be due to true variability in the susceptibility of different components of semantic knowledge. Or, it may be that impairments found in some tasks are the result of the influence of executive functioning (Burke & Peters, 1986; Eustache et al., 1998; Forbes-McKay et al., 2005), which declines with age. It is also possible that peripheral components, such as speech rate, are factors in age-related differences in fluency tasks (Mayr & Kliegl, 2000).

Implicit learning and semantic priming in aging

Findings suggest that smaller age differences exist for tasks of implicit knowledge or incidental learning than explicit memory or intentional learning tasks (Erber et al., 1980; Light & Singh, 1987; Monti et al., 1997). For example, Erber and colleagues found that use of intentional task instructions (e.g., informing participants that they would be asked to later recall words they were rating as pleasant or unpleasant) benefited the young participants significantly more than it did the older individuals. Results from many semantic priming tasks, such as word stem completion (Java & Gardiner, 1991; Light & Singh, 1987), delayed pronunciation (Balota & Duchek, 1988), lexical decision tasks (Bennett & McEvoy, 1999), and two meta-analyses (Laver & Burke, 1993; Myerson et al., 1992) suggest spared implicit memory in late life, with few exceptions (Chiarello & Hoyer, 1988; Davis et al., 1990). That performance on implicit tasks does not reveal large age-related differences prompted its use in the present experiment in the interest of minimizing potential confounding effects of explicit task instruction on the experimental attention tasks.

Implicit semantic priming studies, which are most relevant to the current study, are those that evaluate categorical knowledge. In category exemplar studies, participants are presented with exemplars from various semantic categories during a ‘study’ phase. During the test phase, individuals are instructed to generate words to categorical cues (category headings). Conceptual priming is demonstrated when the number of generated exemplars from the cued category is greater than chance level. Several studies investigating the effects of age on the category exemplar generation task (Light & Albertson, 1989; Mitchell & Bruss, 2003; Monti et al., 2005) fail to find significant age differences, meaning that older adults retain categorical and attribute knowledge of concepts. An exception to this is a possible differential decline that occurs in very late life (80+). In a semantic priming study by Maki and colleagues (1999), decreased priming was evident in the oldest group (80+) when compared to the youngest group but no differences were found between the youngest group and the 70-79 year old group.

This suggests that differences in categorical knowledge may exist in very old cohorts. However, Maki et al. (1999) also found significant correlations between the category exemplar task and measures of explicit memory and semantic fluency tasks. Therefore the effects of age on implicit category knowledge may be the result of the influence of impaired explicit memory or frontal lobe involvement. In reference to the proposed study, we do not posit that individuals over the age of 80 will be disadvantaged as we do not require subjects to generate semantic knowledge nor are individuals asked to make conscious decisions about the semantic information that is presented. The implicit component of semantic priming will minimize the need for frontal lobe involvement.

Animate and inanimate category distinction

Organization of conceptual knowledge into semantic categories has been posited (Ashby et al., 1998; Mervis & Rosch, 1981). The well-defined distinction between the categories of living and non-living items, which has received considerable attention in the semantic literature in recent years, may represent a special dichotomy in categorical knowledge. Category-specific impairments in the naming and recognition of living items, along with spared knowledge of nonliving items, in patients with focal brain damage has been well-documented (Gainotti, 2000; Kurbat, 1997; Laws & Neve, 1999). Similarly, healthy non-neurologically impaired elderly individuals (ages 55-74 & 77-92) may exhibit a greater nonliving than living category effect as revealed in their ability to name more nonliving than living items in one naming task (Coppens & Frisinger, 2005). In the same study, although younger individuals (ages 20-30 years) demonstrated a category effect in favor of nonliving items, results did not reach significance. Some researchers argue that the delineation between these categories is artefactual based on specific semantic attributes (Farah & Wallace, 1992; Lu et al., 2002), grammatical roles, visual complexity of items (Kurbat, 1997), or differential familiarity of words in these two categories.

Neuroanatomical evidence from neurologically impaired, as well as intact individuals, supports the reliance on distinct brain regions for recognition of living versus nonliving items (Caramazza & Shelton, 1998; Strauss et al., 2000). Caramazza and Shelton (1998) argue that the animate/inanimate distinction is based on categorical organization of knowledge in the brain as a result of the evolutionary significance of specific domains. According to their domain-specific model, different categories represent distinct cortical organizations. This supports a distinction between two categories and suggests that the distinction is maintained in later life. In general, it appears that the distinction between these two categories hold a special place in the semantic system. Furthermore, studies thus far suggest relative preservation of semantic skills and preservation of their ability to use categorical knowledge in late life as demonstrated in category exemplar tasks (Light & Albertson, 1989; Mitchell & Bruss, 2003; Monti et al., 2005). With regard to the animate/inanimate distinction, it may be that older individuals show a greater decline in naming for living items as is revealed in one study by Coppens and Frisinger (2005). Further studies are necessary to confirm this finding. For purposes of this study, the abundance of research on these categories and overwhelming evidence of a well-defined distinction between animate and inanimate categories led us to use items from these two categories as our prime words in the semantic orienting task.

Summary

Orienting aligns attention to a location in space allowing for enhanced processing of information at that site. Covert orienting allocates attention without eye gaze to the stimuli. In a traditional cued orienting task, cues that accurately predict the subsequent target location (valid cue) result in faster detection of the visual stimulus occurring at that location than information appearing in uncued (neutral) or unexpected (invalid) sites. Efficiency of orienting can be measured by the magnitude of the validity effect (invalid RT - valid RT), or, facilitory and inhibitory components of orienting can be measured independently by separately assessing RT benefits (neutral RT - valid RT) and RT costs (invalid RT - neutral RT). The magnitude of the validity effect increases in old age (Greenwood et al., 1993; Hartley et al., 1990; Lorenzo-Lopez et al., 2002), which Greenwood and colleagues (1994) posit in one study is due to difficulties disengaging after invalid cueing (i.e., RT costs). However, due to the paucity of research on the "old-old", disengaging skills of this cohort are not known.

Endogenous orienting is associated with top-down processes (Hopfinger et al., 2000) and can occur in response to a symbolic cue, such as an arrow or directive word (e.g., 'left'), or to contingencies between cue and target location (with higher contingencies resulting in higher expectations). Poorer performance of older individuals on endogenous (Greenwood et al., 1993; Greenwood & Parasuraman, 1994; Hoyer & Familant, 1987), but not exogenous orienting tasks (Folk & Hoyer, 1992; Greenwood et al., 1993) suggests that voluntary aspects of orienting are vulnerable to age-related decline. Studies confirm activation of frontal regions of the brain, particularly the dorsolateral prefrontal cortex, in tasks of endogenous orienting (Corbetta & Shulman, 2002; Hopfinger et al., 2000;

Hopfinger et al., 2001). Therefore, it may be that age-related decline in frontal regions of the brain account for the vulnerability of top-down mechanisms of voluntary orienting in late life.

Semantic knowledge, specifically the ability to categorize, remains stable in late life. An association between semantic categories and voluntary covert orienting was researched in a previous orienting study (Lambert & Sumich, 1996) in which individuals were able to learn the implicit relationship between a cue word's category and a predicted target location. This raises the possibility that spared semantic skills in late life may be used to direct visuospatial attention. As peripheral cues were used in the Lambert and Sumich study (1996), attention was captured automatically, and in two of the experiments cue and target locations overlapped spatially, confounding interpretation of use of semantic information. Therefore, the use of semantic categories as predictors of spatial information in an endogenous task is not known and is examined as it relates to both young and older individuals.

Aims and Hypotheses

The current study investigated the effects of age on attention and voluntary orienting using a simple reaction time task and two endogenous covert orienting detection tasks: a traditional symbolic covert orienting task (symbolic COVAT) and a 'semantic' covert orienting task (semantic COVAT). Tasks were administered to three groups of participants: a young group (aged 20-39), a mid-old group (aged 60-79) and an old-old group (aged >80). Two blocks of the SRT task were administered, one at the beginning of the testing session, and the second approximately 45 minutes into the session. Targets were presented centrally without warning following random latencies of 500 ms, 800 ms, 1100 ms, and 1500 ms after trial onset. The symbolic orienting task using a central arrow and peripheral target used probability contingencies of 80/20. In the semantic COVAT, names of animate and inanimate items served as the cues (rather than arrows) and predicted target location based on the same 80/20 contingency: semantic categories predicted target location with 80% accuracy. Screening measures and a battery of standardized neuropsychological tests associated with cognitive domains of attention, speed, language, memory, visuospatial, and executive control functions were administered.

1. **To examine the effects of age on motor speed and variability using a Simple Reaction Time (SRT) task.**

   It was hypothesized that the two older groups would be slower on the SRT than the younger group. Moreover, we hypothesized that the older groups would demonstrate greater RT variability on this task than the younger group. *Significant main effects of group for mean RT and RT variability would support age-related slowing and increased RT variability, respectively. Post-hoc tests demonstrating slower RT for mid-old and old-old groups than the young group [(mid-old = old-old) > young] would support these hypotheses.* Effects of fatigue or practice were assessed by examining the effect of two administrations of the task. It was proposed that faster RT on block 2 than block 1 across all age groups would indicate a practice effect, whereas slower RT on block 2 than block 1 would indicate fatigue.

2. **To examine the age-related effects of voluntary orienting on a symbolic endogenously cued covert orienting task.**

An endogenous covert orienting task was administered with three conditions of a centrally presented cue: 1) valid (arrow) or b) invalid (arrow) in predicting the subsequent target location, or c) neutral (rectangle).

2a. Based on the literature, a robust validity effect (longer RT to invalidly cued trials than validly cued trials) was expected for all groups. In the current study, it was hypothesized that the old-old group would exhibit a greater validity effect than either young or mid-old groups. *Support for this hypothesis would be found with a significant interaction between age and validity. Post-hoc tests would reveal that the old-old group is significantly slower than the younger groups in the invalid condition than in the valid condition.*

2b. It was hypothesized that the old-old group would exhibit greater RT costs (invalid RT – neutral RT), but not greater RT benefits (neutral RT – valid RT) than either young or mid-old groups. *Using calculations of RT costs and RT benefits, support for greater RT costs in the oldest group would be found with a significant main effect of group. In post hoc analyses, we expected to find the RT costs greater in the old-old group than the young and mid-old groups [(young = mid-old) < old-old)].*

3. **To examine whether an association between a semantic category and spatial information can be developed to facilitate voluntary orienting.**

In the Semantic Covert Orienting task, the presence of a validity effect would support that individuals are able to learn the associations between semantic and spatial location. However, as a semantic category has no intrinsic spatial indications, the orienting effect would not be apparent in the initial blocks, but only after multiple trials of exposure have occurred. That is, the relationship between semantic categories and spatial information must be learned before the validity effect becomes evident. Therefore, the 9 trial blocks were collapsed into three segments: early (blocks 1-3), middle (blocks 4-6), and late (blocks 7-9).

3a. It was hypothesized that a validity effect, or RT costs and/or RT benefits would be apparent in middle and late blocks but not in the early block. *Support for the orienting effect would be a significant interaction between validity and block. Post-hoc analyses would reveal that a) RT to the invalid cue condition is significantly slower than RT to the valid cue condition (validity effect) in the mid- and late-blocks than in the early block across all age groups, b) RT to the valid cue condition is significantly faster than RT to the neutral cue condition (RT benefit) in the mid- and late-blocks than in the early block across all age groups, or c) RT to the invalid cue condition is significantly slower than RT to the neutral cue condition (RT costs) in the mid- and late-blocks than in the early block across all age groups.*

3b. It was hypothesized that the validity effect, or RT costs and/or RT benefits would be smaller for older adults (both mid-old and old-old) than the young individuals. As mentioned previously in 3a, it was expected that the effect of cue condition to be ‘learned’ by the middle block and not in the early block; therefore, RT data was collapsed across mid- and late-segments (the early block was eliminated). *Support for this hypothesis would be a significant Group x Cue Type interaction such that the validity effect (or RT benefits or RT costs) is greater in the young cohort compared to the mid-old and old-old individuals.*

3c. The ability to benefit from spatial cues (as in the symbolic COVAT) may indicate intact spatial orienting and be directly related to the ability to benefit from more difficult semantic cues (as in the semantic COVAT). Individuals who do not demonstrate the validity effect in the symbolic task may not be able to benefit from semantic cueing. Therefore, all participants that do not demonstrate the validity effect (with at least a 5 ms difference between valid and invalid trials) were eliminated to minimize confounding affects of non-responders. The same analysis was run as in 3b.

4. **To investigate the relationship between voluntary aspects of covert orienting and standardized neuropsychological tests.**

4a. It was hypothesized that correlations between speed performance on the SRT task and performance on the cognitive domain of speed would reveal faster SRT related to faster speed on standard neuropsychological measures.

4b. It was hypothesized that correlations between performance on the symbolic covert orienting task and neuropsychological measures of executive control and visuospatial functioning would reveal greater RT costs on the orienting task related to lower scores on either tasks of frontal or parietal functioning.

4c. It was hypothesized that correlations between the semantic covert orienting task and neuropsychological measures of semantic skills (e.g., semantic clustering score on the CVLT and semantic fluency) and working memory (e.g., digits backward and spatial span backward) would reveal a smaller validity effect related to lower scores on language functions.

Method

Participants

Recruitment procedures and compensation

Participants were recruited from one of two sites, Queens College-CUNY or Winthrop-University Hospital. Recruitment at Queens College included students in the Psychology 101 subject pool, Adult Education classes, individuals who respond to posted flyers on campus and at local community senior centers, and others referred by word of mouth. Older participants were also recruited through the Division of Geriatrics, Department of Medicine at Winthrop-University Hospital; patients who expressed interest in participating in research were contacted by the investigator to learn about the study and consented to participate. Following consent, brief medical histories were collected to insure inclusionary and exclusionary criteria were met (see below). Approval was granted by the Institutional Review Board (IRB) at Queens College-CUNY and Winthrop-University Hospital.

Participants were compensated in one of two ways: individuals recruited from the Psychology 101 subject pool received credit toward their research requirement; all other individuals were paid $15 for their participation.

Study criteria

Inclusion criteria were: 1) native English speakers (or fluent in the English language by the age of nine), 2) intact cognitive functioning as measured by the Mini Mental Status Exam (MMSE > 25) (Monsch et al., 1995) and Clinical Dementia Rating (CDR=0) (Morris, 1993), 3) normal or corrected visual acuity of 20/40 as measured by the SNELLEN test (Snellen, 1862). Exclusion criteria were*:* 1) history of significant cerebrovascular disease with evidence of stroke or transient ischemic attack, 2) history of neurological disease including Parkinson's or Huntington's disease, epilepsy, or traumatic brain injury with loss of consciousness greater than 20 minutes, 3) diagnosis of Alzheimer's disease, 4) diagnosis of Mild Cognitive Impairment (MCI) or other memory problems), 5) psychiatric disorder, including schizophrenia, depression, bipolar disorder or Attention Deficit/Hyperactivity disorder 6) history of substance abuse or dependence, 7) history of complicated cardiac conditions putting persons at significant risk for cerebral vascular disease (e.g., multiple bypass surgeries with complications), 8) chronic and/or untreated significantly elevated blood pressure, 9) current use of pharmacological treatments that may influence motor or cognitive function (e.g., tricyclic antidepressants, selective serotonin reuptake inhibitors, active chemotherapy, anti-cholinergic therapies including incontinence medication).

Participant recruitment and study entry

One hundred and one individuals were screened and recruited for the study, of which 64 were able to be considered for analysis. Of the 101 screened participants, 28 individuals (27%: 5 young, 15 mid-old, 8 old-old) did not participate, 5 due to scheduling conflicts and 23 for not meeting posted exclusion criteria. Reasons for exclusion were, a) not meeting the language criteria of being fluent in English by age 9 (3 individuals)[1] , b) prior diagnosis of Attention Deficit Hyperactivity Disorder or history of significant attentional difficulties (2), c) significant memory problems (2), d) loss of consciousness lasting longer than 20 minutes (2), f) ongoing treatment with an acetylcholinesterase inhibitor (e.g., galantamine) (1), g) complicated cardiac conditions and/or history of

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[1] All future references to number of excluded individuals will be documented in parentheses with the number only

transient ischemic attacks (5), h) impaired vision with history of macular degeneration, cataracts, or as indicated by score of less than 20/40 on the SNELLEN test in at least one eye (8).

Seventy three individuals signed consent and completed all computer and neuropsychological tasks. Ten of these individuals were eliminated from analyses because they: a) did not meet cut-off scores on screening tests (1 young participant with < 26 on the MMSE and 3 old-old participants with < 135 on the DRS), b) demonstrated poor performance on neuropsychological tests indicative of compromised cognitive functioning (1 young participant with significant perseverations on the CVLT; 1 mid-old and 1 old-old participant with possible Mild Cognitive Impairment as indicated by impaired serial position and delayed memory performance on the CVLT and inability to complete the Trails Test; and c) showed abnormal response patterns on computer tasks (2 old-old individuals with 88% and 72% of total trials eliminated due to anticipatory and/or multiple responses). Multiple responses were also recorded when the participant erroneously pressed the response buttons simultaneously.

The demographic profiles of the 64 individuals who completed all tasks, and whose data were analyzed for the study are reported in Table 1. Multiple one-way ANOVAs were conducted to test for group differences of age, education, estimated IQ, and MMSE scores. Chi square analyses were performed to assess frequency differences in ethnicity, gender, and handedness. T-test comparisons were conducted to test differences in DRS scores in the 2 older groups. One participant was omitted from the DRS comparison because of missing data due to examiner error; her remaining scores were above cut-off.

Table 1

Participant demographics and group characteristics

	Young (n=29)	**Mid-Old (n=20)**	**Old-Old (n=15)**	**Statistic**	***p***
Age	24.55(5.70)	72.05(5.79)	83.47(3.09)	$F(2, 63) = 810.65$[1]	<.001
Age range	20 – 38	61 – 79	80 -89		
Education	14.93(1.33)	17.35(3.03)	14.67(2.44)	$F(2, 63) = 8.65$[2]	<.001
% Caucasian	41.4%	95%	100%	$\chi^2(8) = 26.91$[3]	.001
% Female	72.4%	50%	73.3%	$\chi^2(2) = 3.15$	.207
% Right Handed	93.1%	65%	100%	$\chi^2(4) = 13.95$[4]	.007
Estimated IQ*	103.43(7.65)	115.18(7.54)	111.21(9.00)	$F(2, 63) = 13.75$[5]	<.001
MMSE	28.93(1.10)	28.55(1.36)	28.13(.915)	$F(2, 63) = 2.44$	.095
DRS score	N/A	141.50(2.57)	139.64(2.62)	$t(32) = 2.06$	.048

* Estimated IQ based on NAART

[1] Young < Mid-old < Old-old

[2] (Young = Old-old) < Mid-old

[3] Young < (Mid-old = Old-old)

[4] (Young = Old-old) > Mid-old

[5] Young < Mid-old = Old-old

Apparatus

Equipment

Computerized tasks were programmed by John Zhu at Queens College-CUNY with displays created in Microsoft Paint and PowerPoint. Stimuli were presented on the black screen of a Dell PC with Windows XP operating system and a 17” monitor, at a 1280 by 1024 pixel resolution. Colored toolbars at the top and bottom of the screen were covered with a black Velcro strip. A two-button Logitech mouse fastened in place on the desk served as the response key. Participants were seated 55 cm from the monitor; eye movements were not monitored.

Stimuli

For all three experimental conditions, a centrally presented red plus sign subtending 40’ (or .67°) was used as the fixation. Cue stimuli for the Symbolic COVAT were right- and left-pointing arrows, or an arrow without pointers (neutral cue) subtending 2°. Cue words for the Semantic COVAT, were comprised of three- and four-letters presented in Tahoma 32 regular font lowercase letters, subtending between 2° and 2°and 15’. The target stimulus, an asterisk that subtended 45’ (or .75°), was presented either in the center of the screen (SRT) or with its inner edge 6° from the center (Symbolic and Semantic COVAT).

Measures (see Table 2 for list of measures)

Experimental Speed and Orienting Measures

Simple Reaction Time task (SRT). The SRT is a timed detection task. In this task, two displays were presented (see Figure 1): 1) a central fixation (small red cross) and 2) a central target stimulus (asterisk). Duration between onset of fixation and target onset (SOA: stimulus onset asynchrony) was 500, 800, 1100, or 1500 ms. Participants were instructed to press the mouse button as quickly as possible upon target detection. After response, or 3000 ms if no response was made, the next trial was initiated. Two SRT blocks of 40 trials each were presented, one prior to and one upon completion of the Symbolic and Semantic Orienting tasks.

Figure 1. The two displays of the SRT task: 1) red central fixation and 2) white central target

Symbolic Covert Orienting Task. The computerized Symbolic Covert Orienting task (COVAT) is based on the Cued Target Detection paradigm developed by Posner (1980). Five displays were presented (see Figure 2): 1) central fixation, 2) central cue, 3) central fixation, 4) peripheral target (white asterisk), and 5) blank screen. Cues were valid (arrow accurately pointing to subsequent target location), invalid (arrow inaccurately pointing to subsequent target location), or neutral (rectangle). Six blocks of 34 trials each were administered with 64% valid, 18% invalid, and 18% neutral; valid trials accounted for 79% of the *predictive* cues and invalid for 21% (for more detailed description of percentages, see Appendix A).

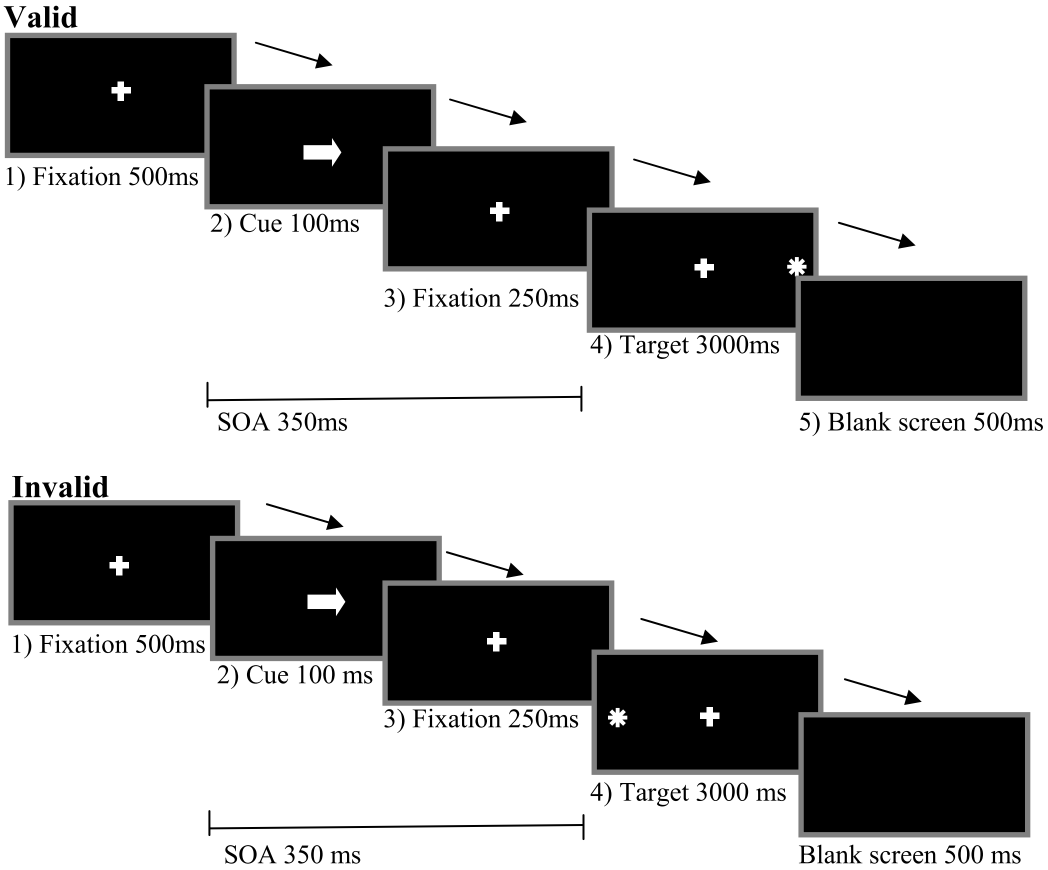

Figure 2. The five displays of the Symbolic COVAT: 1) central fixation, 2) central cue, 3) central fixation, 4) peripheral target, and 5) blank screen

Semantic Covert Orienting Task. The Semantic COVAT is a modification of the Lambert and Sumich (1996) orienting task. There were 5 displays in this task (see Figure 3): 1) central fixation, 2) central cue, 3) central fixation, 4) peripheral target, and 5) blank screen. Following central fixation, cue words appeared and remained on the screen for 100 ms preceding reappearance of the fixation and peripheral right or left targets. The three central cues were: 1) word of a living item, 2) word of a nonliving item, or 3) a "non-word" made up of 3 or 4 "Xs." In this study, the cue word category "predicted" the location of the subsequent target such that a cue belonging to one semantic category predicted which side the target would appear with an 80/20 probability. Because cue words predicted target location, they are referred to as "predictive cues." Non-words ('xxxx') contained no spatial information about subsequent target location and are referred to as "neutral cues." Following a neutral cue, the target was equally likely to appear on the right as on the left side of the computer display. Nine blocks of 50 trials each were administered; valid trials accounted for 80% of the *predictive* cues and invalid for 20% (for detailed description of percentage of valid, invalid, and neutral trials, see Appendix A). More trials were used in the semantic COVAT (i.e., 50 trials) than the symbolic COVAT (i.e., 34 trials) because the association between cue and target was initially not evident and had to be learned.

Cue word stimuli consisted of 10 three-letter animate words, 10 four-letter animate words, 10 three-letter inanimate words, and 10 four-letter inanimate words. All words were nouns and every effort was made to eliminate homonyms (i.e., words that are spelled the same but have different meanings) and homophones (i.e., one of two words that sound the same but have different meanings and/or spelling). Written frequency, familiarity, concreteness, and imageability of each word was collected from the MRC database (Wilson, 1988) and is presented in Appendix B. Animate and inanimate word lists did not differ significantly in any of these characteristics (see Table B3 in Appendix B).

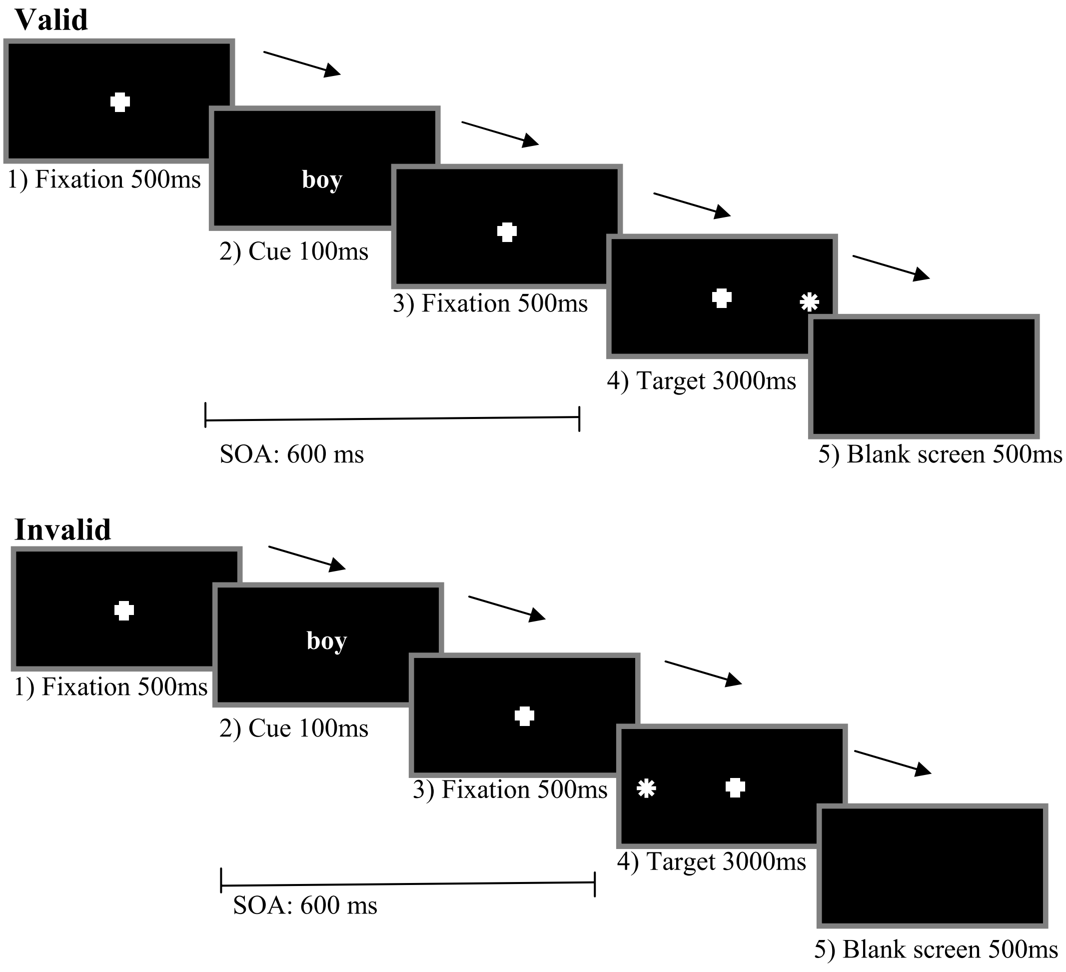

Figure 3. The five displays of the Semantic COVAT: 1) central fixation, 2) central cue, 3) central fixation, 4) peripheral target, and 5) blank screen

Experimental Task Stimuli Presentation

For all three experimental conditions, each trial began with the presentation of the fixation cross in the center of the screen. For the SRT task, this was followed by the centrally presented target after varied SOAs (500, 800, 1100, and 1500 ms). For both the Symbolic and Semantic COVAT, the fixation cross remained on the screen for 500 ms and was followed by the cue stimulus, which remained on the screen for 100 ms and was followed again by the fixation cross. The target was presented on the right or left side of the screen, concurrent with the central fixation cross, after 350 ms SOA for the Symbolic task and 600 ms SOA for the Semantic task. A longer SOA was provided in the semantic COVAT to account for additional time required to process cue words rather than arrow cues. The target remained on the screen for 3000 ms or until the participant responded. After response, the screen remained blank for 500 ms before the next trial began. For the Semantic COVAT, the contingency between cue word category and target location was counter-balanced across groups. For group 1, following an animate cue word, the target appeared on the left on 80% of the trials and the right on 20% and following an inanimate cue word the target appeared on the right on 80% of the trials and the left on 20%; for group 2, the contingencies were reversed. Catch trials were presented with an SOA of 800 ms to limit the regularity of presentation. This was followed by a blank screen for 500 ms and then initiation of the next trial. Practice blocks of 10 trials (SRT task), 22 trials (Symbolic COVAT), or 26 trials (Semantic COVAT) were administered. When necessary, additional practice blocks were allowed.

Cognitive Functioning Measures

Mini-Mental Status Exam (Folstein et al., 1975). This MMSE assesses orientation, registration (learning of three words), attention, recall (memory of 3 words presented earlier), language, and constructional praxis. The purpose of this brief screening measure was to exclude individuals who exhibited compromised cognitive functioning. The cutoff of less than 26 was used as suggested by Monsch and colleagues (1995) to identify patients in the early stages of dementia while accounting for age and education and still maintaining adequate sensitivity and specificity. Max score = 30; cutoff < 26.

North American Adult Reading Test (NAART) (McGurn et al., 2004; Nelson, 1982). The NAART is a modified version of the National Adult Reading test developed specifically for use with the North American population (Blair & Spreen, 1989). As reading skills have been shown to be highly correlated with general intellectual level in the normal population (Spreen & Strauss, 1998), the NAART, rather than the full Wechsler Adult Intelligence Scale (WAIS-III), was used as a measure of estimated general intelligence to reduce total administration time. Results from this measure have been shown to correlate well with scores on the WAIS-R Full Scale IQ (.75) and even higher with the WAIS-R Verbal IQ (.83) (Blair & Spreen, 1989). Furthermore, Uttl (2002) demonstrated that the NAART measures verbal intelligence with comparable accuracy and validity in three different age groups (ages 18-39, 40-59, 60-91), which enabled us to compare scores of the three age groups in our study with reasonable accuracy. For this task, individuals were instructed to read aloud 61 irregular words and were scored for accuracy based on American and Canadian pronunciation (Uttl, 2002). Total number of errors was entered into the following equation developed by Blair and Strauss (Blair & Spreen, 1989) for estimated IQ scores as the dependent measures:

$$\text{Estimated FIQ} = 128.7 - .78(\text{NAART Errors})$$

Visual Functioning Measures

Snellen test (Snellen, 1862). Visual acuity was assessed using the SNELLEN visual eye chart to ensure a minimum of 20/40 vision in each eye with or without corrective eye lenses. It was not deemed necessary to have 20/20 vision in each eye as stimuli on the computer screen are highly discernable and other vision measures were used to assess visual discriminability.

Visual Form Discrimination (Benton et al., 1983). This visual recognition task measures the ability to identify matching complex visual forms. Because participants would be required to discriminate visual stimuli in the computer tasks, this test was administered to ensure adequate discriminability for visual forms. Participants were presented with one target set of stimuli and asked to identify the matching stimulus set from four other sets of designs presented below the target (Lezak, 1995). Sixteen items were administered and participants received full or partial credit for their responses. The outcome measure was total amount correct, with a maximum score of 32. A score of 25 is indicative of “mildly defective” visual perception (Benton et al., 1983).

Attention and Working Memory Measures

Wechsler Memory Scale–III: Digit Span (Wechsler, 1997b). This task was used to assess basic attention span (Lezak, 1995) or “freedom from distractability” (Cohen et al., 2003) to ensure that potential difficulties in experimental tasks of attention were not related to deficits in attentional capacity (Lezak, 1995). In the digits forward task, participants were asked to repeat in the exact order, an increasing number of digits immediately following presentation. Digits backward required participants to recite the string of digits in the reverse order. This component of the task was used as a measure of working memory, purported to involve the ‘central executive’ system, which may be more sensitive to the effects of age or brain dysfunction (Wilde et al., 2004). Maximum digits forward number and maximum digits backward were both converted into z-scores. The digits forward score was averaged with other attention tasks to comprise the “attention” domain and digits backward with other working memory scores to comprise the “working memory” domain.

Wechsler Memory Scale–III: Spatial Span (Wechsler, 1997b). This Spatial Span has been referred to as the “visual analogue” of the digit span task (Wechsler, 1997a), which purportedly “taps the examinee’s ability to hold a visual-spatial sequence of events in working memory and formulate a response based on that information” (Wechsler, 1997a). For this task, the experimenter taps blocks in a prearranged sequence and participants are instructed to reproduce the exact sequence from memory (i.e., forward span) or in the reverse order (i.e., backward span). Maximum spatial span forward score and maximum spatial span backwards score were both converted into z-scores. The forward span was averaged with other attention tasks to comprise the “attention” domain and backward span with other working memory scores to comprise the “working memory” domain.

Language and Semantic Organization Skill Measures

Controlled Oral Word Association Test (COWAT) (Benton & Hamsher, 1976). The primary purpose of the COWAT is to measure language function and capacity for semantic categorization. Word generation to letter cues involves naming as many words as participants are able to think of in 60 seconds that begin with the letters ‘F’, ‘A’ or ‘S’ (Lezak, 1995). Instructions prohibit use of the same word with different suffixes, proper nouns, and numbers. The semantic COWAT was also administered, in which participants were asked to name as many items as possible in 60 seconds from the following categories: animals, fruits, and vegetables. The total number of admissible responses from the FAS task and semantic COWAT were converted into z-scores. The COWAT score was used in two separate domain scores: it was averaged with the FAS score to comprise the “language” domain and also with other semantic scores to comprise the “semantic organization” domain.

Memory

California Verbal Learning Test II (CVLT-II) (Delis et al., 2000). The CVLT-II assesses explicit learning of information, implicit learning of semantic categories, and conceptual organization skills (Lezak, 1995). For this task, participants were instructed to listen to a list of 16 words comprised of items from four different semantic categories. They were asked to repeat as many words as they remembered after each of the five presentations, and after short-and long-delays with interference from a second list of words. As a measure of the rate of learning (Delis et al., 2000), the sum of trials one through five (total immediate recall), as well as short- and long-delay scores were converted to z-scores and averaged to comprise the "memory" domain. Furthermore, since use of semantic clustering as a learning strategy would indicate intact capacity for semantic categorization—an important component of the Semantic COVAT—the semantic cluster score was also used as a dependent variable. The raw score was converted into a z-score and averaged with other semantic tasks to comprise the "semantic clustering" domain. The scaled score of the learning slope was transformed into a z-score and used as the dependent variable of "learning."

Frontal/Executive Function Measures

DKEFS Color-Word Interference Test (Delis et al., 2001) . A measure of cognitive flexibility and inhibition, the Stroop test is often used to assess one's ability to suppress an automatic response for a less habitual one. The modified version (Delis et al., 2001) with four parts was administered because of its additional component that evaluates the ability to shift between types of responses. In the first and second parts of this task, participants were instructed to name patches of randomized colors (red, green, blue) as quickly as possible and read aloud the names of three different words printed in black ink respectively as baseline measures of color naming and reading speed. In the third condition, they were asked to name the ink color of incongruent words (e.g., the word "green" printed in the color "red") and in the fourth condition, a further instruction included reading the word when surrounded by a box, and reading the ink color when not boxed. The total number of completed items as well as two types of errors, uncorrected and self-corrected, were recorded by the examiner. Scaled color naming and letter reading scores were converted into z-scores and averaged with other speeded tasks to comprise the “speed” domain.

DKEFS Trail Making Test (Delis et al., 2001). The 5-part DKEFS Trail Making Test was used in this study to assess cognitive flexibility and switching. Participants were administered five different tasks that included visual scanning, number sequencing, letter sequencing, number-letter switching and motor speed. The skills involved in the number-letter switching condition are associated with those implicated in multi-tasking, simultaneous processing, and divided attention while difficulties are linked to deficits in frontal lobe function (Delis et al., 2001). Scaled contrast scores [(inhibition minus color naming) & (inhibition/switch minus combined color naming + word reading)] were converted into z-scores and averaged with other frontally mediated tasks to comprise the “executive function” domain. The scaled motor speed scores were converted into z-scores and averaged with other speeded tasks to comprise the “speed” domain.

Dementia Screening Measures

Dementia Rating Scale (Mattis, 1988). This scale is used to screen for the presence of dementia by evaluating five areas of cognition that are sensitive to change in dementing diseases (Lezak, 1995). Each participant was asked to answer questions or follow commands within each of the following domains: (1) attention, (2) initiation and perseveration, (3) construction, (4) conceptualization, and (5) verbal and non-verbal short-term memory (Spreen & Strauss, 1998). A cutoff score of 135 (Chan et al., 2001) was used to indicate the presence of cognitive impairment.

Clinical Dementia Rating (Morris, 1993). The Clinical Dementia Rating scale is a standard ranking of functional change in older individuals. From semi-structured interviews and observations during administration of tests, the examiner rates the participants' ability to function within the domains of: (1) Memory, (2) Orientation, (3) Judgment and Problem Solving, (4) Community Affairs, (5) Home and Hobbies, and (5) Personal Care. Scores of the CDR are generated and ranked as 0, 0.5, 1, 2, 3, 4, and 5. A score of 0.5 is used to identify persons with questionable dementia (Morris et al., 1995) who may or may not convert to AD; therefore, a CDR score of 0 was required for participation in this study.

Table 2

Neuropsychological and Experimental Measures

TASK	Duration of task
General Cognitive Functioning	
Mini Mental Status Exam (Folstein et al., 1975)	5-10 minutes
North American Adult Reading Test (Blair & Spreen, 1989)	< 5 minutes
Visual function	
SNELLEN test (Snellen, 1862)	2 minutes
Visual Form Discrimination (Benton et al., 1983)	10 minutes
Attention	
Digit span WMS-III (Wechsler, 1997b)	5 minutes
Spatial Span WMS-III (Wechsler, 1997b)	5-10 minutes
Semantic organization	
Semantic COWAT (Benton & Hamsher, 1976)	5 minutes
CVLT-II – semantic clustering score (Delis et al., 2000)	40 minutes
Language	
Phonemic COWAT (F, A, S) (Spreen & Strauss, 1998)	5 minutes
Semantic COWAT (Benton & Hamsher, 1976)	5 minutes
Executive Function	
Color-Word Interference Test – DKEFS (Delis et al., 2001)	10 minutes
Trail Making Test – DKEFS (Delis et al., 2001)	
Dementia Screening	
Dementia Rating Scale (Mattis, 1988)	10-15 minutes
Clinical Dementia Rating (CDR) (Morris, 1993)	5 minutes
Computerized Experimental Tasks	
Simple Reaction Time task	2 minutes
Symbolic Orienting Task	10 minutes
Semantic Orienting Task	20 minutes

Procedure

Each participant signed the written consent, was asked about their medical and mental health to detect the presence of any condition that would warrant further exclusion from the study, and completed the SNELLEN eye test. Individuals were alternately assigned to one of two counterbalanced conditions (Groups 1 & 2) for the Semantic COVAT. Participants were given a brief introduction to the study and an overview of the experimental task conditions. They were seated 55 cm from the monitor, instructed to keep their eyes fixed on the ‘fixation point’ at the center of the screen at all times, and asked to respond to target stimuli by pressing the response key with the index finger of their dominant hand as quickly as possible (right-handed participants used the left button and left-handed individuals used the right button) upon detection of the target. Explicit instructions were given to respond ***after*** the appearance of the target to minimize anticipatory responses and were repeated throughout the session as necessary. For the Covert Orienting tasks, participants were informed of the displays that would be presented (e.g., that they would see a red cross, cue stimulus, and target) but were not informed that cues predicted target location. For the Symbolic COVAT, they were told that cues would be right- and left-pointing arrows and in the Semantic COVAT that cues consisted of words of living and non-living items. Participants were then presented with a reminder of the directions on the computer screen as follows:

> *This is the start of the next task. Please remember to keep your eyes fixed on the '+' at the center of the screen at all times. Press the mouse button as quickly as possible when you see the target. Click the mouse key when you are ready to begin.*

Upon completion of the Semantic COVAT, participants were asked a series of questions (see Appendix C) to assess whether they became aware of the relationship between the semantic cues and spatial location of the target.

After completing all computerized tasks, individuals were administered the remainder of the neuropsychological test battery and additional computer tasks that were part of a larger study. Neuropsychological testing was administered by one of two trained graduate students, and computerized tests were administered by one of four trained individuals. Order of administration of experimental and neuropsychological tasks is presented in Appendix D. Testing for younger individuals took approximately 2-½ hours and was broken up over two separate days. Because of more restrictive schedules and difficulties with traveling, testing for older individuals was scheduled on a single day; administration time for older individuals was between 2-½ and 3 hours.

Experimental Design

For the SRT condition, two 3 x 2 x 4 mixed-design ANOVAs were performed with age (3: young, mid-old, old-old) as the between-group factor, and block (2: block 1, block 2) and SOA (4: 500ms, 800ms, 1100ms, 1500ms) as the within-subject independent variables. Speed was examined using mean RT as the dependent variable in the first analysis, and variability in the second analysis using RT standard deviation as the dependent measure.

For the Symbolic COVAT, mean RT data was first submitted to a 3 x 2 mixed-design ANOVA using age (3: young, mid-old, old-old) as the between group factor and cue validity (2: valid, invalid) as the within subject independent factor. The validity effect "difference score" (invalid RT – valid RT) was then computed and entered into a one-way ANOVA. To examine RT costs and RT benefits separately, mean RT data was submitted to a 3 x 3 mixed-design ANOVA using age (3: young, mid-old, old-old) as the between group factor and cue validity (3: valid, neutral, invalid) as the within-subject factor. Difference scores for RT costs (invalid RT – neutral RT) and RT benefits (neutral RT – valid RT) were computed and entered into separate one-way ANOVAs.

In the Semantic COVAT, RT data was subjected to 3 mixed-design ANOVAs: 1) 3 x 3 x 3 mixed repeated measures ANOVA with age (3: young, mid-old, old-old) as the between group factor and cue validity (3: valid, neutral, invalid) and block (3: early, mid, late) as the within subject independent variables. 2) After eliminating segment 1 (blocks 1-3), blocks 4-9 were collapsed and mean RT was submitted to a 3 x 3 mixed-design factorial ANOVA with age (3: young, mid-old, old-old) as the between-group factor and validity (3: valid, neutral, invalid) as the within subject factor. 3) Finally, individuals who did not exhibit a validity effect on the symbolic COVAT were eliminated from analysis. Remaining RT data was submitted to a 3 x 3 mixed-design factorial ANOVA with age (3: young, mid-old, old-old) as the between-group factor and validity (3: valid, neutral, invalid) as the within subject factor.

Data Analysis

Statistical analyses were carried out using SPSS 11.5 software (SPSS Inc., 2002) and Statistica 6 (StatSoft, 2003).

Inspection of RT data was performed to determine normal distribution and/or degree of deviance from normal distribution. To adjust for skewed RT distributions, log transformations on RT data were computed and submitted to the same analyses as RT data. Differences between transformed and untransformed data were not found; therefore, all results are reported as mean untransformed RT. In addition, RT variability was calculated as the standard deviation of each participant's untransformed RT values and was also submitted to SRT analyses.

Significance was determined with alpha level set at .05 and effect size is reported as partial eta-squared. Greenhouse-Geisser corrections were applied for all effects involving SOA (SRT task). Least significant difference (LSD) post hocs were used unless otherwise indicated.

Pre-analysis data management

A two-pass procedure was used to insure that RT data excluded anticipatory responses, response errors, and significant outliers. In the first pass all trials with no response, multiple responses, and responses with RT < 100 ms were eliminated. In the second pass, outlier trials were removed: individual subject RT distributions were subjected to z-score transformations and RTs greater or less than 3 standard deviations (SD) from the mean were eliminated. A summary of the percent of trials eliminated from total number of responses for each task is presented in Appendix E. Data from 2 participants were excluded from SRT analyses[2].

Results

Hypothesis 1a: individuals in the mid-old and old-old groups will be significantly slower than the young group in a Simple Reaction Time task (SRT).

Mean reaction time data from the SRT task was submitted to a 3 x 2 x 4 mixed-design factorial ANOVA with group (3: young, mid-old, old-old) as the between-group factor and block (2: block 1, block 2) and SOA (4: 500 ms, 800 ms, 1100 ms, 1500 ms) as the within-subject independent factors (see *Table 3*). Means and standard error scores of significant effects are reported in Appendix F.

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[2] Reasons for exclusion from SRT task: one young participant was excluded for missing data due to computer malfunction; one old-old participant was excluded because RT values of block 1 were 2.5 times greater than block 2 (786 ms vs. 303 ms), and were inconsistent with all other RT performances (i.e., orienting tasks RT range: 267–593 ms). Thus, block 1 was considered an anomaly and excluded.

Table 3

Mixed factorial ANOVA for Simple Reaction Time task; DV = Mean RT

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	809135.328	2	404567.664	6.607	.003	.183
Error	3612990.035	59	61237.119			
SOA	407898.657	1.915[1]	213055.131	74.971	.000	.560
Group x SOA	5137.216	3.829[1]	1341.645	.472	.748	.016
Error (SOA)	321002.442	112.957	2841.817			
Block	83320.199	1	83320.199	7.457	.008	.112
Group x Block	107177.485	2	53588.742	4.796	.012	.140
Error (Block)	659275.217	59	11174.156			
Block x SOA	18620.900	2.206[1]	8441.491	5.701	.003	.088
Group x Block x SOA	20382.125	4.412[1]	4619.957	3.120	.014	.096
Error (Block x SOA)	192713.581	130.147[1]	1480.740			

[1] Greenhouse-Geiser adjusted degrees of freedom reported for all effects involving SOA

There was a significant main effect of group, *F(*2, 59) = 6.607, *p* =.003. Post-hoc tests revealed slower RT for the mid-old and old-old groups than the young group *(p* =.01 & *p* =.002, respectively). There was no difference between the 2 older groups *(p* =.38). A significant effect of SOA, *F(*1.92, 112.96) = 74.971, *p* < .001, was found. Post-hocs indicated slower RT following SOA 1 (500 ms) than SOA 2 (800 ms: *p* < .001), consistent with the psychological refractory period (PRP) phenomenon, and longer RT to SOA 2 than both SOA 3 and SOA 4 *(p* =.002 and *p* < .001, respectively). No differences were found between the two longest SOAs (SOA 3 and SOA 4: *p* =.37). While the effect and subsequent post-hoc analyses of block, *F(*1, 59) = 7.457, *p* =.008 indicated that RT in the second block was slower than RT in the first block *(p* =.04), the Group x Block interaction, *F(*2, 59) = 4.796, *p* =.012 indicated that slowing from block 1 to block 2 was age-group specific. Post-hoc tests demonstrated that the mid-old and old-old groups were slower in block 2 than in block 1 *(p* =.01 & *p* =.02, respectively), but the young participants were faster in block 2, although not significantly so *(p* =.38). A Block x SOA interaction, *F(*2.21, 130.15) = 5.701, *p* =.003, was found. Post-hocs revealed greater differences between consecutively longer SOAs in block 2 than block 1. That is, while significantly shorter RT to SOA 2 than SOA 1 was evident in both blocks (both *p* < .001), the shorter RT to SOA 2 than SOA 3 was significant in block 2 only *(p* < .001), not block 1 (10.99; *p* =.07). There were no significant differences between SOA 3 and SOA 4 in either block (block 1: *p* =.60; block 2: *p* =.27). The Group x Block x SOA interaction, *F(*4.41, 130.15) = 3.120, *p* =.014 (see Figure 4) indicated that this increased difference between consecutive SOAs in block 2 than block 1 was greater for the oldest group than the other 2 age groups. For both the young and mid-old groups, RT was significantly faster at SOA 2 than SOA 1 in both blocks (all: *p* < .001), but the significant decrease from SOA 2 to SOA 3 was evident in block 2 only (young and mid-old: *p* =.03), and not block 1 (young: *p* =.16; mid-old: *p* =.15). No differences were found from SOA 3 to SOA 4 in either block (young block 1: *p* =.61 and block 2: *p* =.76; old block 1: *p* =.51 and block 2: *p* =.60). The oldest group was significantly slower on SOA 1 than on SOA 2 in both blocks (block 1: *p* =.005 and block 2: *p* <.001), but only in block 2 was the RT slower on SOA 2 than SOA 3 *(p* =.03) and SOA 3 than SOA 4 *(p* =.01); this was not the case in block 1 *(p* =.83 and *p* =.70 respectively). This indicated that the overall slowing of block 2 was a) disproportionately worse in the old-old and b) adversely affected not only the PRP of the shortest SOA (SOA 1), but also SOA 2 and 3, which was not the case on the first administration of block 1.

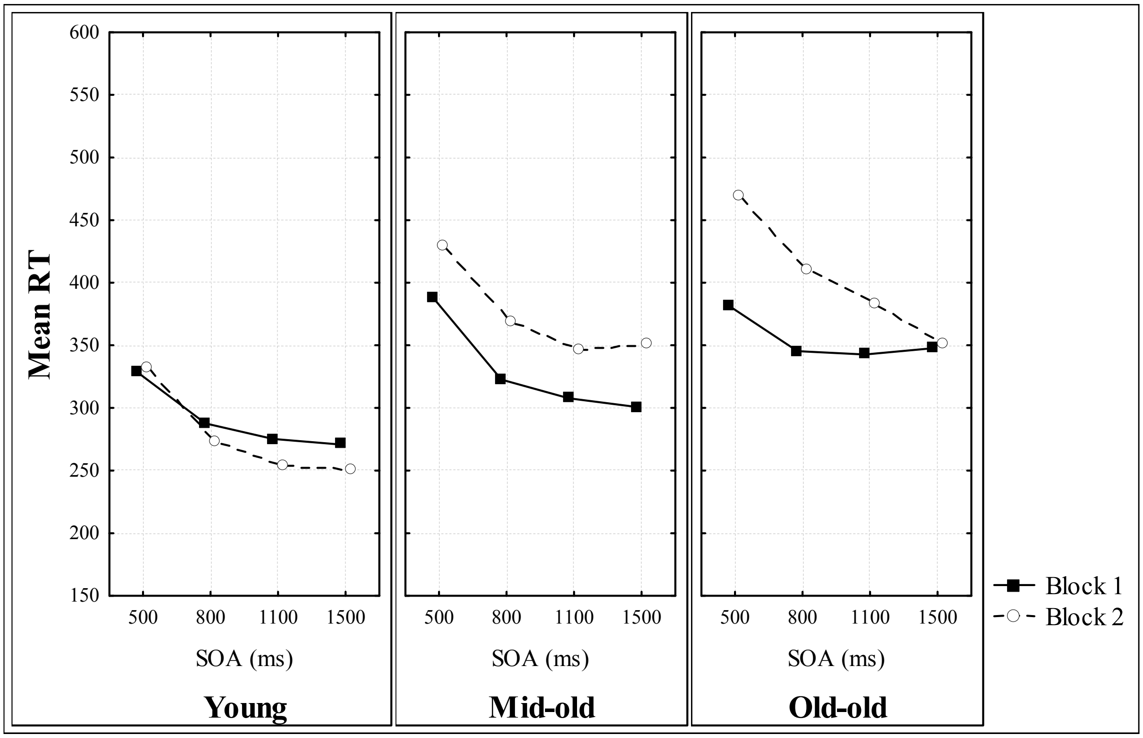

Figure 4. Graph of significant Group x Block x SOA interaction (SRT)

Hypothesis 1b: individuals in the mid-old and old-old groups will show significantly greater RT variability in the SRT task.

A 3 x 2 x 4 mixed-design factorial ANOVA was conducted with group (3: young, mid-old, old-old) as the between-group factor and block (2: block 1, block 2) and SOA (4: 500 ms, 800 ms, 1100 ms, 1500 ms) as the within subjects independent factors and RT variability as the dependent variable (see Table 4).

Table 4

Mixed-factorial ANOVA for Simple Reaction Time task; DV = RT variability

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	107183.632	2	53591.816	5.704	.005	.162
Error	554341.554	59	9395.620			
Block	3319.389	1	3319.389	1.084	.302	.018
Group x Block	3127.162	2	1563.581	.511	.603	.017
Error (Block)	180585.305	59	3060.768			
SOA	26951.636	2.194[1]	12281.853	7.563	.001	.114
Group x SOA	10247.955	4.389[1]	2334.995	1.438	.221	.046
Error (SOA)	210264.082	129.471[1]	1624.022			
Block x SOA	573.020	2.252[1]	254.443	.207	.838	.003
Group x Block x SOA	8942.237	4.504[1]	1985.353	1.613	.168	.052
Error (Block x SOA)	163536.637	132.871[1]	1230.792			

[1] Greenhouse-Geiser adjusted degrees of freedom reported for all effects involving SOA

As expected, there was a significant main effect of group, *F(*2, 59) = 5.70, *p* =.005. Post-hoc tests revealed greater RT variability in the old-old group and mid-old group than in the young group *(p* =.01 & *p* =.005 respectively). No differences were found between the two older groups *(p* =.99). An effect of SOA, *F(*2.194, 129.47) = 5.56, *p* =.001, was found. Post-hoc tests indicated that RT was more variable at the shortest SOA than all other SOAs (*SOA 2*: *p* =.003; *SOA 3*: *p* =.002; *SOA 4*; *p* < .001). There were no other significant differences.

Hypothesis 2a: individuals in the old-old group will exhibit a greater validity effect than either the young or mid-old groups on a Symbolic COVAT test.

Preliminary analyses were conducted to test for group differences due to target location (left vs. right) and to order of block presentation (blocks 1-6). RT data were submitted to a 3 x 2 mixed design ANOVA with group (young, mid-old, old-old) as the between-group factor and target location (left, right) as the within subject factor. While there was a main effect of group, *F(*2, 61) = 9.41, *p* < .001, with young faster than mid-old and old *(p* = .001 & < .001, respectively) and no differences between older groups *(p* = .621), there were no significant differences between right and left target location, *F(*1, 61) = .60, *p* =.441, or Group x Target Location interaction, *F(*2, 61) = 1.36, *p* =.265. The 3 (group) x 6 (block) mixed design ANOVA revealed a significant group effect, *F(*2, 61) = 9.318, *p* < .001, also with young faster than mid-old and old-old *(p* = .001 & *p* < .001, respectively) and no differences between the older groups *(p* = .633). No effect was found for block, *F(3.701*, 305) = 1.25, *p* =.29, or interaction between group and block, *F(*10, 305) = 1.42, *p* =.171.

Mean RT was submitted to a 3 x 2 mixed-design factorial ANOVA with group (3) as the between-group factor and cue type (2: valid, invalid) as the within subject independent factor (see Table 5).

Table 5

Mixed factorial ANOVA for Symbolic COVAT (valid/invalid cues); DV = mean RT

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	209628.028	2	104814.014	8.426	.001	.216
Error	758771.293	61	12438.874			
Cue Type (valid/invalid)	48941.162	1	48941.162	97.793	<.001	.616
Group x Cue Type	4107.017	2	2053.508	4.103	.021	.119
Error (Cue Type)	30527.985	61	500.459			

There was a main effect of group, *F(*2, 61) = 8.426, *p* =.001. Post-hoc tests indicated that the two older groups were slower than the young group (mid-old: *p* =.003; old-old: *p* =.001). No differences were found between the two older groups *(p* =.470).

The effect of cue type, *F(*1, 61) = 97.793, *p* < .001 revealed faster RT on valid than invalid trials *(p* < .001). The Group x Cue Type interaction, *F(*2, 61) = 4.10, *p* = .021, indicated that the difference between RT to valid and invalid trials was greater in the old-old group than in the young and mid-old groups. To further investigate this interaction, a 'validity effect' difference score (invalid RT – valid RT) was computed and entered as the dependent variable into a one-way ANOVA. The significant validity effect, *F(*2, 61) = 4.10, *p* = .021, and subsequent post-hocs revealed that the magnitude of the validity effect was greater for the old-old group than the young group *(p* =.041) and the mid-old group *(p* =.027) (see Figure5). No significant differences were found between the young and mid-old groups *(p* =.921).

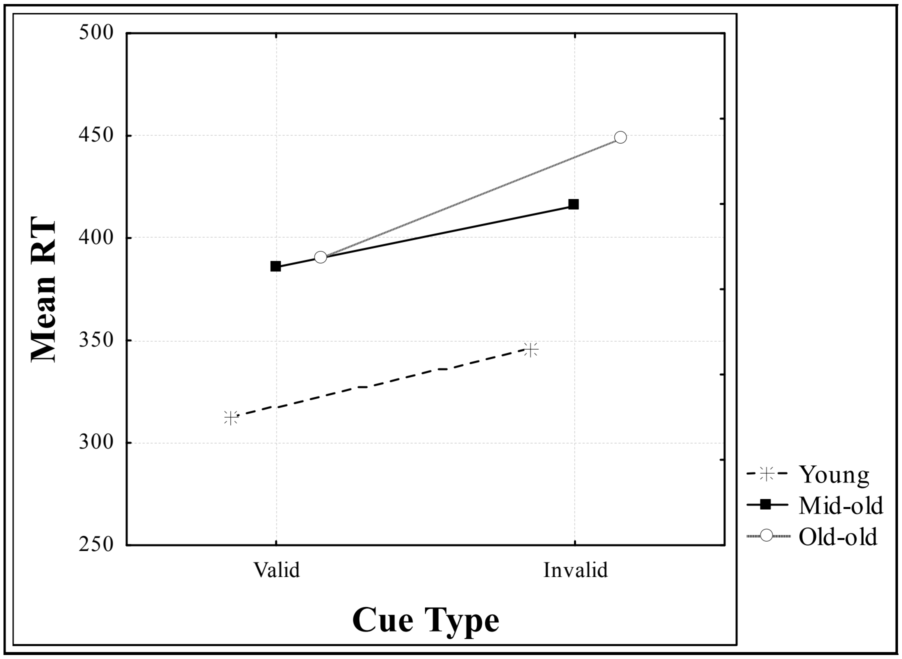

Figure 5. Graph of significant Group x Cue Type interaction (symbolic COVAT)

Hypothesis 2b: individuals in the old-old group will exhibit greater RT costs (invalid RT – neutral RT), but not greater RT benefits (neutral RT – valid RT) than either young or mid-old groups on a Symbolic COVAT test.

Mean RT scores were submitted to a 3 x 3 mixed-design factorial ANOVA with group (3) as the between-group factor and cue type (3: valid, neutral, invalid) as the within subject independent factor (see Table 6).

Table 6

Mixed factorial ANOVA for Symbolic COVAT (valid/neutral/invalid cues); DV=mean RT

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	356414.63	2	178207.32	9.634	.000	.240
Error	1128412.03	61	18498.56			
Cue Type (valid/neutral/invalid)	56257.22	2	28128.61	50.003	.000	.450
Group x Cue Type	6917.94	4	1729.48	3.074	.019	.092
Error (Cue Type)	68629.66	122	562.54			

The main effect of group, *F(*2, 61) = 9.63, $p < .001$ indicated that the two older groups were slower than the young group (mid-old: p =.002; old-old: $p < .001$). No differences were found between the two older groups *(p* =.399). Post-hoc tests following the effect of cue type, *F(*2, 61) = 50.00, $p < .001$ revealed faster RT on trials with valid cues than trials with neutral and invalid cues (both $p < .001$). No significant differences were found between neutrally and invalidly cued trials *(p* =.099). However, the interaction between group and cue type, *F(*4, 122) = 3.07, $p = .019$ indicated that the difference in RT to neutral and invalid cues varied as a function of age group: while RT to neutral and invalid trials did not differ in the two older groups *(p* =.89 & *p* =.51), RT was significantly slower to invalid than neutral trials in the young group *(p* =.03), indicative of significant costs for this age group only (Figure 5). Pairwise comparisons also revealed that group differences varied as a function of cue type. That is, significant group differences were found for neutral cues, with young faster than the mid-old and old-old groups *(p* = .04 & *p* = .01), but not between the older groups *(p* = .53). No group differences were found for valid or invalid conditions.

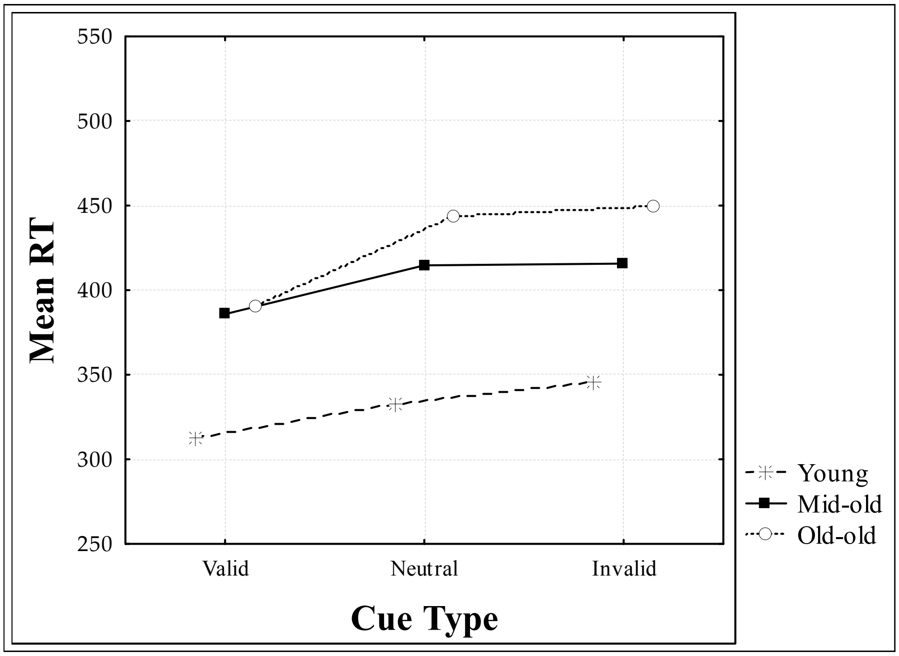

Figure 6. Graph of significant Group x Cue Type interaction (symbolic COVAT)

The differences of cue type were also represented by computation of difference scores for RT benefits (neutral RT – valid RT) and RT costs (invalid RT – neutral RT), which were submitted to separate one-way ANOVAs (See Table 7).

There was a significant RT benefit, *F(*2, 61) = 3.733, *p* =.030. Post-hoc analyses revealed that the valid to neutral cue difference was greater in the old-old group than the young group *(p* =.023). No significant differences were found between the young and mid-old group *(p* =.699) or between the mid-old and old-old groups *(p* =.163). No significant effects were found for analysis on RT costs, *F(*2, 61) = 1.001, *p* =.373.

Table 7

One-way ANOVAs for RT benefits and RT costs; DV = mean RT

Source		**SS**	**df**	**MS**	**F**	***P***
RT benefit	Between Groups	10638.23	2	5319.115	3.733	.030
	Within Groups	86921.21	61	1424.938		
RT cost	Between Groups	1901.55	2	950.773	1.001	.373
	Within Groups	57911.79	61	949.374		

Hypothesis 3a: a validity effect will be apparent in middle and late blocks of the Semantic COVAT but not in the early block

Preliminary analyses were conducted to test for differences of the counterbalanced subgroups, target location (left vs. right), order of block presentation (blocks 1-9), and effects of cue-category (animate vs. inanimate). Effect of counterbalanced group was analyzed by submitting mean RT to an independent samples t-test, which revealed no significant differences, *t(*62) = 1.10, *p* =.276. A 3 x 2 mixed design ANOVA with group (3) as the between-group factor, target location (2: left, right) as the within subjects factor and mean RT as the dependent variable revealed a main effect of group, *F(*2, 61) = 5.187, *p* = .008 with young faster than mid-old *(p* = .031) and old-old *(p* = .004) and no differences between older groups *(p* = .36). There was no main effect of target location (left vs. right), *F(*1, 61) = .96, *p* =.327 or interaction effect, *F(*2, 61) = .767, *p* = .469. Effect of block presentation was analyzed by submitting the mean RT data to a mixed-design factorial ANOVA with group as the between group factor (3) and block (9) as the within subject factor. A main effect for group was significant, *F(*2, 56) = 4.79, p= .012, but not for block, F(8, 448) = .56, p =.812. A Group x Block interaction, F(16, 448) = 2.83, p < .001 was significant. To better understand the interaction, mean RT data from each group were submitted to separate repeated measures ANOVAs which revealed a main effect for block in the young, F(8, 208) = 6.29, p < .001, but not the mid-old, F(8, 152) = .417, p =.91, or the old-old group F(8, 88) = .823, p =.585. Within the young group there were significantly longer RTs to blocks 1, 2, and 3 than to all other 6 blocks, suggesting that there were either learning or practice effects. Finally, a 3 x 3 mixed-design ANOVA was conducted with group (3) as the between group factor, cue type as the within subject factor (animate, neutral, invalid), and RT as the dependent variable. A significant effect of group, F(2, 61) = 5.229, p = .008 was found. Post-hoc tests revealed faster performance in the young group than the mid-old (p = . 032) and old-old groups (p = .004) but no differences between the older groups (p = .344) and the effect of cue type F(2, 122) = 4.56, p =.012, and subsequent post-hocs indicated that RT was slower to non-word cues (‘xxxx’) than animate (p =.027) and inanimate cue words (p =.009). No differences were found between animate and inanimate words (p =.441).

Mean RT was submitted to a 3 x 3 x 3 mixed-design factorial ANOVA with group (3) as the between-group factor and segment (3: early, middle, and late) and cue type (3: valid, neutral, invalid) as the within subject independent factors (See Table 8).

Table 8

Mixed factorial ANOVA for Semantic COVAT (with 3 segments); DV = mean RT

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	451970.091	2	225985.046	5.130	.009	.144
Error	2686902.530	61	44047.582			
Segment	3683.993	1.300	2833.631	.943	.358	.015
Group x Segment	17245.673	4	4311.418	2.206	.072	.067
Error (Segment)	238427.220	122	1954.321			
Validity	2085.981	2	1042.991	5.599	.005	.084
Group x Cue Type	1079.918	4	269.980	1.449	.222	.045
Error (Cue Type)	22726.871	122	186.286			
Segment x Cue Type	446.247	3.164	141.019	.532	.671	.009
Group x Segment x Cue Type	3371.453	8	421.432	2.008	.046	.062
Error (Segment x Cue Type)	51206.094	244	209.861			

The effect of group, *F(*2, 61) = 5.13, *p* =.009 and post-hocs indicated that the two older groups were slower than the young group (mid-old: *p* =.031; old-old: *p* =.004). No differences were found between the two older groups *(p* =.373). There was main effect of cue type, *F(2*, 122) = 5.60, *p* =.005. Post-hoc analyses revealed slower RT on trials with neutral than valid *(p* =.004) and invalid cues *(p* < .012). There were no differences between RT to validly and invalidly cued trials *(p* =.904). Although we find a Group x Segment x Cue Type interaction, *F(*8, 244) = 2.01, *p* =.046, a validity effect was not evident in any of the segments and therefore does not support this hypothesis.

Hypothesis 3b: the significant validity effect (or separate RT costs and/or RT benefits) will be smaller for older adults (both mid-old and old-old) than the young individuals.

Responses from the first segment (blocks 1-3) were eliminated as these were predicted to be a learning period for all participants, and data from the second two segments were collapsed. RT data were entered into a 3 x 3 mixed design ANOVA with group (3) as the between-group factor and cue type (3: valid, neutral, invalid) as the within-subject independent factor (See Table 9).

Table 9

Mixed factorial ANOVA for semantic COVAT; DV = mean RT

Source	**SS**	**df**	**MS**	**F**	***p***	**η^2**
Group	154007.944	2	77003.972	5.188	.008	.145
Error	905390.471	61	14842.467			
Cue Type	599.006	2	299.503	5.257	.006	.079
Group x Cue Type	322.616	4	80.654	1.416	.233	.044
Error (Cue Type)	6950.689	122	56.973			

There was a significant effect of group *F(*2, 61) = 5.188, *p* =.008. Post-hoc tests revealed slower RT for the mid-old and old-old groups than the young group *(p* =.033 and *p* =.004, respectively). No significant differences were found between the 2 older groups *(p* =.35). The effect of cue type was significant, *F(*2, 122) = 5.26, *p* =.006, indicating that RT to neutral trials was slower than both valid *(p* =.01) and invalid trials *(p* =.011). However, we found no validity effect (valid RT < invalid RT) as a main effect *(p* = .977) or in an interaction with group (Group x Cue Type interaction), *F(*4, 122) = 1.416, *p* = .233.

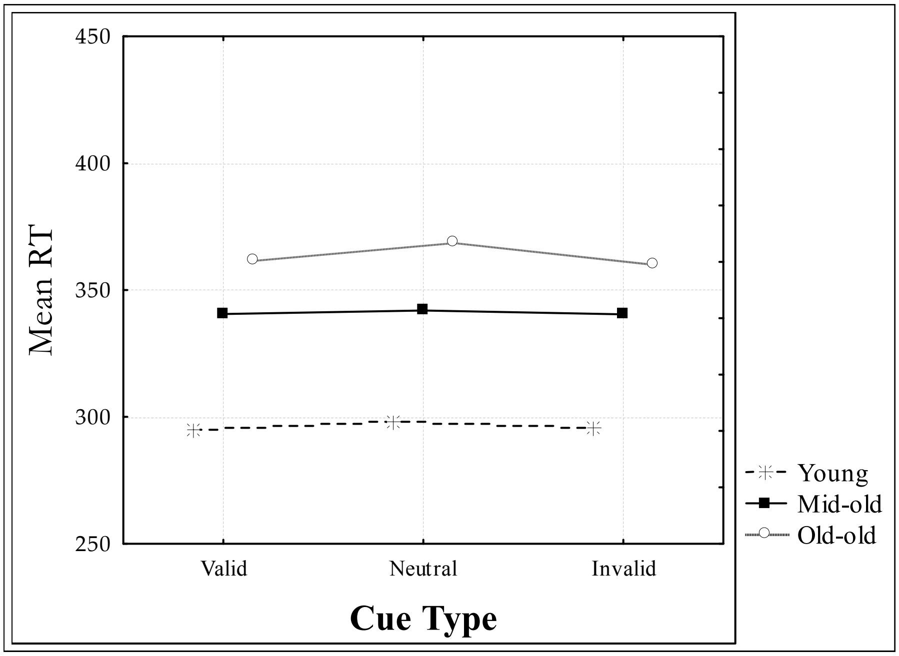

Figure 7. Graph of significant Group x Cue Type interaction (semantic COVAT)

Hypothesis 3c: a significant validity effect will be evident after eliminating data from participants who did not get the validity effect in the symbolic COVAT.

Mean RTs from the 58 participants who demonstrated a validity effect in the symbolic COVAT were submitted to a 3 x 3 mixed-design factorial ANOVA with group (3) as the between-group factor and cue type (3: valid, neutral, invalid) as the within subject independent factors (see Table 10). A significant effect of group, *F(*2, 55) = 4.54, *p* =.015 revealed slower RT for the mid-old and old-old groups than the young group *(p* =.031 and *p* =.008, respectively). No significant differences were found between the 2 older groups *(p* =.579). There was a significant effect of cue type, *F(*2, 110) = .16, *p* =.046; subsequent post-hocs revealed slower RT to neutral trials than valid *(p* =.044) and invalid trials *(p* =.043). Again, we found no validity effect as a main effect *(p* = .78) or in an interaction with group (Group x Cue Type interaction), *F(*4, 110) = 1.826, *p* = .129.

Table 10

Mixed factorial ANOVA for semantic COVAT; DV = mean RT

Source	**SS**	**Df**	**MS**	**F**	***p***	**η^2**
Group	141747.322	2	70873.661	4.536	.015	.142
Error	859392.939	55	15625.326			
Cue Type	374.765	2	187.382	3.163	.046	.054
Group x Cue Type	432.663	4	108.166	1.826	.129	.062
Error (Cue Type)	6516.152	110	59.238			

Hypothesis 4a: RT from the SRT task will be correlated with speed of processing on neuropsychological tasks as measured in the speed domain[3]*.*

It was also of interest to examine whether there was a relationship between performances on the SRT task and other cognitive functions: domain scores of attention, memory, language, visuospatial, and executive functioning scores were calculated. In addition, domain scores were calculated for learning and semantic clustering to use in correlations with the Semantic orienting task. Domain scores were derived from the average of the z-scores from composite neuropsychological measures. For a list of composite tasks for each domain see Appendix G. Mean scores and standard deviations for each domain are reported in Appendix H.

Domain scores and overall RT from the SRT task were submitted to the Pearson Product Moment Correlation; Bonferroni corrections (significance set at $p < .008$) were used to accommodate increased number of tests. Both the young and mid-old groups

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[3] Domain scores: neuropsychological tasks that measure speed were converted to z-scores and averaged into a single domain. Higher speed domain scores reflect faster RT and lower scores on the SRT reflect faster RTs. Thus, faster speed in both speed domain and SRT is represented by a negative correlation.

showed a significant relationship between speed of performance on target detection and the speed domain (r = -.693 and r = -.755 respectively) indicating that faster speed on the SRT was associated with faster speed on the composite of speed measures (e.g., DKEFs Color-Word Interference, color naming; DKEFs word reading; DKEFS Trails, motor speed). It should be noted that scores on the speed domain did not differ between groups and the youngest group was the slowest on this composite score followed by the mid-old group and the old-old group although no differences were significant. SRT speed of performance and the attention domain were also correlated in the mid-old group (r = -.615) such that higher scores in the attention domain were associated with faster RT. There were no significant relationships between RT and domain variables for the old-old group.

Because time of administration (block 1 vs. block 2) impacted RT performance on the SRT task, blocks 1 and 2 were submitted to Pearson Product Moment correlations as separate variables (significance set at $p < .007$). The young group demonstrated a significant relationship between the speed domain and both blocks of the SRT task (r = -.658 and -.653, respectively), again such that faster RT on cognitive measures were associated with faster speed on the SRT task. The mid-old group showed a relationship between the speed domain and performance on the SRT task in block 2 (r = -.841) such that faster SRT performance was associated with faster speed on the neuropsychological measures of speed, but block 1 did not reach significance (r = -.535, n.s.). The mid-old group also demonstrated correlations between the attention domain[4] and the SRT task in

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[4] Domain scores: the neuropsychological tasks that measured attention were converted to z-scores, with greater z-scores reflecting better performance. On the other hand, low scores on the SRT task reflect faster RTs. Thus, the relationship between better attentional performance and faster RT would be represented with a negative correlation.

block 1 (r = -.687) but not block 2 (r = -.458). Here, better performance on the attention measures was associated with faster speed on the SRT. It should be noted that the r values are high, but stringent Bonferroni corrections minimize significance. No significant relationships were found in the old-old group in either block.

Hypothesis 4b: performances in the Symbolic COVAT will be correlated with domain scores of executive control or visuospatial functioning such that greater RT costs on the orienting task are associated with lower scores on tasks of frontal or parietal functioning.

Using Pearson Product Moment Correlation, correlations between performance on the symbolic orienting task (validity effect, RT costs, and RT benefits) and cognitive domain scores (attention, memory, language, speed, visuospatial and executive function) did not reach significance with Bonferroni correction significance set at $p < .008$. Relationships that neared significance were found: between executive functioning and RT benefits in the mid-old group (r = -.512; $p = .03$) such that better performance on executive functioning measures was associated with smaller RT benefits, and between executive functioning and the validity effect (r = -.586; $p = .022$) and RT costs (r = -.646; $p = .009$) in the old-old group, with higher scores in executive functioning associated with smaller validity effect and smaller RT costs.

Hypothesis 4c: performances in the Semantic COVAT will be positively correlated with domain scores of working memory (e.g., digits backward and spatial span backward) and semantic skills (e.g., semantic clustering score on the CVLT and semantic fluency) such that smaller validity effect is associated with lower scores on working memory and language functions.

These correlational analyses were not conducted because a validity effect was not found in the Semantic COVAT.

Discussion

The current study assessed visual attention and covert orienting in young, mid-old and old-old age groups of healthy participants. Participants were tested on three experiments, a simple detection task (SRT), and two covert orienting tasks (COVAT), one with a centrally presented arrow cue (Symbolic), and the other with a centrally presented word whose semantic category indicated target location (Semantic). Cognitive domain scores derived from standard neuropsychological tests were used to determine if underlying cognitive processes contributed to performance on these experimental attention tasks.

The findings recapitulated the commonly observed effects of age-related slowing, but revealed that an overall slowing hypothesis (Salthouse & Somberg, 1982) could not account for all results. Although response times of the young group were indeed faster than mid-old and old-old groups, no significant differences were found between the two older groups in any of the experiments. Three significant interactions, however, did reveal dissimilarities among all groups, but only under particular conditions. The first interaction (SRT, Group x Block) showed that while the old-old group was slower than the young group throughout the testing session, the mid-old group matched the speed of the young group on the first administration, but was unable to maintain this faster level of performance on the repeated presentation. The second (SRT, Group x Block x SOA) demonstrated that very rapid successive presentation times between stimuli on the SRT task disproportionately slowed the old-old group, especially on the second administration.

The third interaction (symbolic COVAT, Group x Cue Type) showed that while all groups showed a traditional validity effect, the old-old group had the largest validity effect and benefited significantly more from valid arrow cues not only relative to invalid cues, but also relative to neutral cues. Together, these results suggest that fatigue (effect of repeated block) and task load (effect of short SOA) imposed higher attentional demands on the old-old group, who may need to use all available cues to aide their performance (beneficial effect of valid cues). Correlations between RT performance and neuropsychological domain scores suggested differences in the way that participant groups performed these tasks. Older individuals may alter their strategies in order to manage increasing task demands. That is, they may need to recruit additional neural mechanisms (Cabeza, 2002), and draw on helpful cues to compensate for their difficulties. The third experiment, Semantic COVAT, showed similar group effects on speed of performance, but no validity effect was observed, indicating that individuals were unable to benefit from contingencies in semantic categories and spatial location of targets in this endogenous semantic orienting task.

The findings of these experiments fulfilled some of our original hypotheses, but others were not supported.

Hypothesis 1

The first hypothesis predicted that older groups would be slower and more variable on SRT performance. This hypothesis was supported with significant main effects of group; post-hoc analyses showed that the two older groups were slower (Hypothesis 1a) and more variable (Hypothesis 1b) than the young group. Our results corroborate previous literature of age-related slowing (Der & Deary, 2006; Filley & Cullum, 1994;

Pierson & Montoye, 1958; Salthouse, 1993a; Salthouse, 1993b) and increased RT variability in later life (Botwinick & Thompson, 1968; Deary & Der, 2005; Der & Deary, 2006; Pierson & Montoye, 1958). It should be noted, however, that a generalized slowing hypothesis (Cerella et al., 1980; Salthouse & Somberg, 1982) would predict that the old-old group would perform even more slowly than the mid-old group. This was not fully supported by our data, for while the mean RT of the mid-old group was faster (mean 352 ms) than the old-old group (mean 379 ms), the difference was not significant. The lack of power due to small sample size may have accounted for the non-significance; however other factors contributing to this performance should be entertained. These possibilities are discussed.

Effects of repeated administration

One of the contributing factors that disproportionately affected the older groups was the effect of repeated administration. It should be noted that the second administration of the SRT task in this study is not immediately repeated, as is often done in other reaction time studies (Gottsdanker, 1982; Ratcliff et al., 2001; Smith & Brewer, 1995), but occurred 45 minutes after other computer and neuropsychological testing. First, the finding of a main effect of block and subsequent post-hoc tests revealed that participants performed more slowly on the second SRT administration than the first, but the group by block interaction revealed that this was the case only for the two older groups. During the first administration, the young group was fast (mean RT, 290 ms); they maintained their speed, and were even faster on the second administration (mean RT, 278 ms). The mid-old group was similarly fast for block 1 (mean RT, 330 ms), but slowed on block 2 (mean RT, 374ms), and the old-old group was slow at first (mean RT, 354 ms) and even slower on the second administration (mean RT, 403 ms). Thus, performances of the young and mid-old groups were similar and both significantly faster than the old-old group on first administration, but by the second administration performance of the mid-old was more like the old-old group.

Fatigue

One possibility that might account for the slowed performance in both older groups on the second SRT administration was vulnerability to fatigue. Fatigue is defined by Dirnberger and colleagues (2004) [p. 26] as a "subjective feeling of weariness, tiredness, or lack of energy" and effects may include slowed RT on simple detection (Boksem et al., 2006) and choice tasks (Boksem et al., 2005), and increased RT variability on a simple detection task (Boksem et al., 2006). Fatigue is also associated with depleted dopaminergic function, known to decrease in late life (Severson et al., 1982). Thus, fatigue may be one explanation of the slower performance on the second administration. However, there were some findings that do not support a theory of fatigue. First, RT variability did not increase across the two blocks. Second, the speed on the orienting tasks (symbolic and semantic COVAT) did not get progressively slower over the testing session. Lastly, we did not obtain corroborating evidence from self-report measures which could have evaluated subjective feelings of fatigue. Nonetheless, vulnerability to fatigue needs to be entertained as an explanation of the slowed performance of the older individuals.

Strategy

Another possibility to account for slowed performance could be a shift in the strategy, or the way the task was performed. The correlations between SRT performance and neuropsychological domains illustrated different patterns of performance for each age group, and suggested that the groups used alternate strategies to perform the task. It was hypothesized that neuropsychological tests of speed (e.g., motor speed-Trails; word reading-DKEFs Color-Word Interference and color naming- DKEFs Color-Word Interference) would correlate with performance speed on the SRT task (Hypothesis 4a), and the findings support this hypothesis, but not for all groups. In the young group, performance in the speed domain did correlate with SRT performance throughout the entire session, but in the mid-old group it correlated only in the second block. For the mid-old group, SRT performance on the first block correlated with performance on standard measures that tap attentional capacity (e.g.., digit span-WAIS and spatial span-WAIS). In the old-old group, SRT performance was not correlated with any cognitive domains at all. Thus, even when group speeds were equivalent (e.g., young and mid-old on SRT-Block 1), the correlations indicated that alternate strategies were invoked to perform the same task. This suggests a shift in strategy by the mid-old group, which may be a way to compensate for their age-related changes. It may be that performance speed in the young group is faster and more automatic, but for mid-old participants to maintain speed, they need to recruit additional attentional resources. When the mid-old group did not draw on these attentional mechanisms (e.g., in block 2), and they reverted to the automatic speed mechanisms used by the young group, their performance slowed to the level of the old-old group. For the old-old group, it remains unclear whether the automatic, or resource recruiting mechanisms are being employed; whatever their strategy, their performance is significantly slower than the young group on both administrations and the first administration of the mid-old group.

Effects of load

A second factor that disproportionately affected performance speed was load of information. In the SRT experiment, load is operationalized using the SOA variable: when the SOA was short, information had to be processed more rapidly and this represented a type of higher load. The significant main effects of SOA revealed longer RTs and increased RT variability following the shortest SOA (500 ms), and progressively shorter RTs and decreased RT variability as SOA increased. This validated the Psychological Refractory Period (PRP) effect (Telford, 1931; Welford, 1952), which is the delay in responding to the second of two stimuli presented in rapid succession caused by the time required to "reset" from processing of the first item (Allen et al., 1998; Glass et al., 2000; Theeuwes et al., 2004). While the PRP effect was evident across all three groups (SOA main effect), and across all groups on both administrations (Block x SOA), the Group x Block x SOA interaction showed that repeated administration *and* short SOA disproportionately affected the old-old group. When attention load was highest (SOA 1), the old-old group showed a significantly greater RT difference between block 1 and block 2 (mean 89 ms) compared to the young group (mean 5 ms) and mid-old group (mean 42 ms). (See Figure 4 in Result section: 3-way interaction). Prior studies have demonstrated age-related slowing on PRP effects (Allen et al., 1998; Hartley & Little, 1999), but the current study shows how the PRP effect combined with fatigue may selectively exacerbate performance. Thus, while fatigue reduced the performance speed of the mid-old group but not the young group, the compounded effects of higher load *and* fatigue was most detrimental to the old-old group.

Hypothesis 2

The second hypothesis predicted a greater validity effect in the old-old group than the young and mid-old groups in a traditional symbolic covert orienting task (Hypothesis 2a). This hypothesis was supported by the findings. As in the SRT task, the young group was faster than both mid-old and old-old groups, who were not significantly different from one another [young < (mid-old=old-old)]. There was the expected main effect of cue type (valid < invalid), with faster RTs after validly than invalidly cued trials, demonstrating that the central arrow acted to orient attention to the peripheral target (Posner, 1980). The group by cue type interaction revealed that the magnitude of the difference between RT to valid and invalid trials (i.e., the magnitude of the validity effect) was greatest in the old-old group [(young = mid-old) < old-old]. These group interactions initially appeared to support our prediction (Hypothesis 2b) of age-related difficulties with disengagement. That is, disproportionate slowing occurs in invalidly cued trials due to increasing difficulty disengaging from the invalid cue (Greenwood & Parasuraman, 1994). We had predicted that the old-old group would demonstrate greater RT costs but not RT benefits than the young and mid-old groups. However, our analyses with the neutral cue dispelled this. Separate examination of RT costs (invalid RT – neutral RT) and RT benefits (neutral RT – valid RT) revealed that all three groups benefited from spatially predictive cues, with faster RT to valid than neutral trials. RT benefits were greatest in the old-old group, which differed significantly from the young group, and were greater but not significantly different from the mid-old group; equivalent performances were found in the young and middle groups [(young < old-old) = mid-old]. Contrary to our hypothesis of greater RT costs in the old-old age group, only the young group exhibited RT costs, a finding that challenges the concept of an age-related disengagement deficit. One explanation for the greater benefits in the old-old group was that they strategically allocated attentional resources to maximize facilitation, perhaps as an attempt to compensate for their overall decrease in performance speed. Support for this interpretation is found in a covert orienting study that examined the effects of cues and prompts in younger and older individuals (Hartley et al., 1990). RT to valid, neutral and invalid cues was measured but only the combined effect of costs plus benefits (validity effect) was analyzed. Hartley and colleagues posited that the finding of a greater validity effect (invalid RT – valid RT) in older participants is consistent with age-related slowing but that the greater relative proportion of costs and benefits (validity effect over valid RT) supports equivalent, or possibly better, allocation of attentional resources. Because they did not analyze RT data from the neutral cue, the effects of RT benefits (neutral RT – valid RT) could neither confirm nor refute their interpretation. The current study, however, does look at the RT difference to valid and neutral cues and finds greater RT benefits in the old-old; we propose that with age, individuals may ‘accentuate the positive’ in order to use their attentional resources efficiently. An alternate explanation of the RT benefits may be that for the old-old group the neutral cue acted like an invalid cue. The neutral cue is intended to be spatially uninformative (e.g., a box with no arrow) providing neither predictive nor false information about the location of the subsequent target. It appears to function as such in prior studies (Parasuraman et al., 1992; Posner, 1980) and in this experiment’s young group. However, when the target appears after a centrally presented neutral cue, and fixation and attention remain central, disengagement from that central location has to occur: this could elicit a longer RT for older participants. Therefore, the neutral cue might operate ‘neutrally’ for the young, but not the older participants, for whom it operates much like an invalid cue. In fact, some researchers (Jonides & Mack, 1984) argue against the use of neutral cues because they may not lead to the same level of alertness and may require additional processing time than informative cues. This explanation might account for the lack of RT costs in the two older groups, but not for the young group, [young < (mid-old = old-old)]. Previous functional imaging and lesion studies (Corbetta et al., 2000; Posner et al., 1984; Posner et al., 1987) and studies using patients with Alzheimer’s disease (Parasuraman et al., 1992) implicate parietal regions in target detection at invalidly cued locations. Although linking behavioral data to neuroanatomy is beyond the scope of this study, if the neutral cue is acting in a manner similar to the invalid cue, we could speculate that posterior parietal regions would subserve disengagement from both neutral and invalid cueing in older adults. To our knowledge this has not been investigated.

It was initially hypothesized (Hypothesis 4b) that correlations between the symbolic orienting task and neuropsychological domain scores would reveal that greater RT costs were associated with poorer performance on tasks of switching and inhibition (executive functioning domain) or standard tasks that tap parietal functions (visuospatial domain). However, the lack of significant RT costs in the older group undermined any findings associated with this measure. In fact, correlations between performance on symbolic orienting and the cognitive domain scores did not reach significance for any group. It should be noted that significance criteria were stringent to correct for multiple test comparisons ($p < .006$). Using more lenient criteria ($p < .05$) (Larzelere & Mulaik, 1977), two relationships were significant: in the mid-old group, better executive functioning was correlated with greater RT benefits (p = .03) and in the old-old group, better executive functioning was correlated with a greater validity effect.

Hypothesis 3

The third hypothesis predicted a significant validity effect, RT costs, and/or RT benefits in the semantic orienting task for all groups following a period of exposure, when participants could learn the association between semantic category and target location. This hypothesis was partially supported by the data. The young group did have faster RTs compared to the mid-old and old-old group [young < (mid-old = old-old)] and RT was slower to neutral than valid cues (RT benefit), but results indicated that participants were unable to learn the association between cue word category and target location—no group showed any validity effect. The slower RT to neutral than valid cues without a concurrent validity effect is not interpreted as being due to facilitation based on the semantic category of the cue word. Furthermore, the validity effect was not observed in any other analyses involving the Semantic COVAT test and failed to support the prediction that the validity effect would be greater in young than mid-old and old-old groups (Hypothesis 3b), even after eliminating participants who did not demonstrate the validity effect in the symbolic task (Hypothesis 3c). We therefore failed to replicate the findings of Lambert and Sumich (1996). However, in two of the three studies by Lambert and Sumich, the semantic cue and target were both presented peripherally. This spatial overlap may have confounded the effect of cue validity. In the third experiment, cue words appeared to the right and left of fixation and the targets above or below fixation. Although the cues and targets never appeared in the same location, they did appear peripherally and perhaps activated the exogenous orienting system. Cue words in the current study were presented centrally making this an entirely endogenous task, and possibly making the cue-target relationship too difficult to learn. Due to the null findings on the Semantic COVAT, correlations were not conducted for this experiment.

The results of the present study suggest that increasing age was associated with changes in attention and voluntary orienting. The SRT and symbolic COVAT tasks are two measures that tap distinct attentional systems, the SRT thought to be related more to alerting and the COVAT tasks more to orienting. Performance from this study showed that both tasks had the similar overall patterns of faster performance in the young than the mid-old and old-old groups. But, while the two older groups' overall speeds looked equivalent, there was a shift with age. Older adults were more affected when demands were high, they used compensatory strategies to reallocate attentional resources, or they optimized favorable conditions to offset some late life slowing. The older cohorts were also different than the young when they were fatigued; an effect that was exacerbated in the old-old group when compounded by presentation of stimuli in rapid succession. In the absence of corroborating imaging data, it is unclear whether the greater validity effects in the old group can be attributed to the similar disengaging difficulties that relate to impaired parietal functioning in lesion patients (Corbetta et al., 2000; Posner et al., 1984), to frontal system decline (Dempster, 1992; West, 1996), or to changes in the efficiency of allocating attention (Hartley et al., 1990). The current findings and the correlation data suggest that alternate strategies were employed in older participants, and hence alternate underlying neural mechanisms were likely used. We also saw that the mid-old group showed the change in strategy in one but not another condition, perhaps representing the transition to the old age strategy. The recruitment and reorganization of attentional mechanisms through life mimics functional reorganization on other cognitive tasks (e.g. verbal learning) that has been documented with neuroimaging (Cabeza, 2002). The current studies have helped to delineate what aspects to investigate in future imaging corroborations.

Limitations of this study

There were several limitations to the current study. The first is the small sample size of the older groups, which was due in part to stringent exclusion criteria imposed to minimize the chances of using participants with compromised cognitive functioning. This might have limited the statistical power of our analyses. Second, the age range for each group was 20 years, a span that may have been too broad to capture age-related changes, particularly in the young group where group differences were observed for participants over 30 compared to those less than 30 years old.

Another limitation is the generalizability of our findings to the general population. The young cohort was comprised mostly of psychology students who participated for class credit. The older participants were recruited primarily from adult education classes at Queens College, another group-specific cohort - of well educated individuals. Older participants were also recruited via referrals from primary physicians at Winthrop-University Hospital, visiting local senior centers and posting flyers in the local community. While additional recruitment sites might have enhanced the chances of obtaining a more diverse group, all procedures targeted actively involved, motivated members of the community, who may not be representative of the older population as a whole. Also, the two older cohorts were comprised of an ethnically homogenous sample. Furthermore, the stringent exclusionary criteria discussed earlier resulted in a bias for "optimally healthy" older individuals without any evidence of MCI or AD and who may not be representative of that age group in the general population.

Group differences in demographic characteristics, specifically with regard to level of education and estimated IQ, may also have confounded interpretation of effects. Total years of education were found to be higher in the mid-old group than the other two groups with no differences between young and old-old [mid-old > (young = old-old)] and estimated IQ was higher in the two older groups when compared to the young but equal to one another [young < (mid-old = old-old)]. Cautions against inappropriate use of analysis of covariance (Miller & Chapman, 2001) due to limitations in this technique dissuaded us from statistically controlling for these effects. However, results should be viewed with caution as level of education and IQ might have factored into our significant findings.

Summary and future directions

This study was designed to investigate spatial attention and voluntary orienting across the lifespan. Results from the SRT task and symbolic orienting task, as well as correlations with cognitive domain scores, indicated that the transition from young adulthood to late life is accompanied by decreased speed and changes in visual attention. Performance speed of older individuals decreased as a function of repeated administration and decreased SOA. Future behavioral studies of the effect of fatigue and interaction with higher load demands are needed to better understand this relationship. We also found evidence of shifts in attentional allocation and the implementation of strategies to compensate for this age-related decline. The HAROLD model (Cabeza, 2002) proposes that older individuals recruit additional neuroanatomical regions to perform the same tasks that younger individuals perform. Corroboration of our findings with functional imaging data might support our hypothesis that the alternate strategies are subserved by different neural mechanisms. The present research provides evidence for late life changes in the voluntary orienting paradigm with a greater validity effect in the old-old group resulting more from facilitation of valid cueing than costs of invalid cueing. Future studies should look to replicate the findings of increased benefits.

Appendices

Appendix A: Percentages of valid, neutral, and invalid trials

Symbolic Covert Orienting Task

	Number of trials	**Percent of "predictive" trials**	**Percent of all trials**
		PREDICTIVE CUES	
Valid		**79%**	**64%**
Non-catch	20		
*Catch	2		
Invalid		**21%**	**18%**
Non-catch	4		
*Catch	2		
		NON-PREDICTIVE CUES	
Neutral			**18%**
Non-catch	4		
* Catch	2		

* Catch trials were used to limit the regularity of presentation; total # of catch trials = 6 (18%)

SEMANTIC COVERT ORIENTING TASK

	Number of trials	**Percent of "predictive" trials**	**Percent of all trials**
		PREDICTIVE CUES	
Valid		**80%**	**64%**
Non-catch	26		
Catch	6		
Invalid		**20%**	**16%**
Non-catch	6		
Catch	2		
		NON-PREDICTIVE CUES	
Neutral			**20%**
Non-catch	8		
Catch	2		

* Catch trials were used to limit the regularity of presentation; total # of catch trials = 10 (20%)

Appendix B: Lists of cue words for Semantic COVAT and their characteristics

Table B1: List of animate words

Word	Concreteness	Familiarity	Imageability	K-F frequency[5]
Baby	589	597	608	62
Bird	602	592	614	31
Boy	609	606	618	242
Cat	615	582	617	23
Cow	621	529	632	29
Dog	610	598	636	75
Fish	597	548	615	35
Fox	605	501	607	13
Frog	619	507	617	1
Girl	607	645	634	220
Hen	631	461	597	22
Lady	564	573	571	80
Lamb	633	519	614	7
Lion	627	511	626	17
Man	618	623	567	1207
Owl	614	477	595	2
Pig	614	509	635	8
Pony	611	524	642	10
Rat	624	548	588	6
Wolf	595	537	610	6

Table B2: List of inanimate words

Word	Concreteness	Familiarity	Imageability	K-F frequency
Ball	615	575	622	110
Bed	635	636	635	127
Boat	637	584	631	72
Boot	595	566	604	13
Car	622	634	638	274
Desk	583	583	574	65
Fork	592	584	598	14
Hat	611	580	562	56
Jar	595	564	571	16
Key	612	603	618	88
Kite	592	481	624	1
Lamp	615	578	575	18
Pan	586	566	532	16
Pen	571	554	576	18
Pie	613	576	604	14
Rock	600	583	612	75
Rope	608	539	596	15
Rug	611	557	591	13
Shoe	600	569	601	14
Van	606	542	572	32

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[5] "K-F frequency refers to written frequency as obtained from the norms of Kucera and Francis (1967)."

Table B3: T-tests for cue word category characteristics

	Statistic	***p***
Concreteness	t(38) = 1.13	.265
Familiarity	t(38) = -1.74	.091
Imageability	t(38) = 1.99	.054
K-F frequency	t(38) = .85	.400

Appendix C: Questions following Semantic Covert Orienting task

1. Did you notice anything about the words in that task?
2. Please tell me all the words you can remember from that task?
3. While you were carrying out the experiment, were you aware of any relationship between the words and the location of the target?

   YES / NO

   a. If YES please describe this relationship (continue overleaf if necessary).
4. I'm going to read you two pairs of statements concerning the experiment you just performed. Your task here is to decide which of them is true. Listen to them both and then choose one.
   a. If the word referred to something living, the target usually appeared on the right side and if the word was the name of something non-living, the target was usually on the left side.
   b. If the word referred to something living, the target usually appeared on the left side and if the side word was the name of something non-living, the target was usually on the right side.
   c. Please indicate your confidence in the judgment you have just made by choosing one.

      I feel that my choice in (3) was:

      A. a pure guess
      B. mainly guesswork
      C. possibly the correct choice
      D. probably the correct choice
      E. very likely the correct choice
      F. almost certainly the correct choice

Appendix D: Order of presentation of Experimental tasks

One block (40 trials) of the SRT

Nine blocks (50 trials each) of the Semantic Covert Orienting task

Six blocks (34 trials each) of the Symbolic Covert Orienting task

One block (40 trials) of the SRT

*Note: Because the association between cue words and spatial location was intended to be an implicitly learned relationship, it was important that participants were not given any clues about the spatial nature of the cues. For this reason, the order of the two Covert Orienting tasks were not counterbalanced and the Semantic task always preceded the Symbolic Covert Orienting task.

Typical administration of neuropsychological measures

Young adults: Day 1
Digit Span
CVLT (free & cued recall; short-delay)
Spatial Span
DKEFs Color-Word Interference Test
CVLT (long-delay free & cued recall; recognition)
DKEFS Trail Making Test
Visual Form Discrimination
Day 2
Mini-Mental Status Exam
NAART
COWAT

Mid-old and Old-Old groups
Digit Span
CVLT (free & cued recall; short-delay)
Spatial Span
DKEFs Color-Word Interference Test
CVLT (long-delay free and cued recall; recognition
DKEFS Trail Making Test
Visual Form Discrimination
Mini-Mental Status Exam
NAART
COWAT
Dementia Rating Scale
Clinical Dementia Rating

Appendix E: RT data characteristics for SRT task

Simple Detection Task

	Young (n=28)	**Mid-old (n=20)**	**Old-old (n=14)**	χ^2	***p***
Multiple responses	0.6%	2.3%	1.1%	23.06	< .001
No responses	0.0%	0.3%	0.2%	5.23	.073
Anticipatory responses	0.0%	0.4%	.4%	5.80	.055
-3 s.d. < Z-score > +3 s.d.	1.7%	1.9%	1.7%	0.239	.887

Symbolic COVAT task

	Young (n=29)	**Mid-old (n=20)**	**Old-old (n=15)**	χ^2	***p***
Multiple responses	1.1%	0.6%	1.6%	15.62	< .001
No responses	0.0%	0.0%	0.2%	9.30	.01
Anticipatory responses	0.7%	0.7%	1.2%	6.97	.031
RTs 3SD above/below mean	1.6%	1.4%	1.5%	0.31	.856

Semantic COVAT task

	Young (n=29)	**Mid-old (n=20)**	**Old-old (n=15)**	χ^2	***p***
Multiple responses	0.9%	1.9%	4.5%	232.80	< .001
No responses	0.0%	0.0%	0.2%	35.10	< .001
Anticipatory responses	0.7%	0.4%	.4%	10.66	.005
RTs 3SD above/below mean	1.5%	1.3%	1.3%	1.00	.607

Appendix F: Means tables for SRT task [Mean RT (Standard Error)]

Table F1

Main effect of group

Group

Age group	
young	284.17 (16.53)
mid-old	351.75 (19.56)
old-old	378.78 (23.83)

Table F2

Main effect of block

Block

Block	
1	324.75 (12.47)
2	351.72 (12.67)

Table F3

Main effect of SOA

SOA

SOA	
1	387.92 (13.80)
2	334.68 (12.25)
3	318.09 (10.62)
4	312.27 (11.34)

Table F4

Group x Block interaction

Block	**Young**	**Mid-old**	**Old-old**
1	290.49 (17.84)	329.59 (21.11)	354.18 (25.23)
2	277.86 (18.12)	373.92 (21.44)	403.38 (25.62)

Table F5

Block x SOA interaction

SOA	**Block 1**	**Block 2**
1	365.41 (15.50)	410.42 (14.74)
2	318.57 (12.77)	350.79 (13.67)
3	308.60 (12.18)	327.58 (11.47)
4	306.43 (12.07)	318.11 (13.53)

Table F6

Group x Block x SOA interaction

Age group		**SOA 1**	**SOA 2**	**SOA 3**	**SOA 4**
Young	Block 1	328.16 (22.17)	287.66 (18.27)	275.33 (17.41)	270.81 (17.26)
	Block 2	332.77 (21.08)	273.32 (19.55)	254.01 (16.41)	251.33 (19.37)
Mid-old	Block 1	387.14 (26.30)	322.67 (21.61)	307.71 (20.61)	300.83 (21.43)
	Block 2	428.97 (24.94)	368.88 (23.13)	346.21 (19.41)	351.64 (22.92)
Old-old	Block 1	380.94 (31.35)	345.38 (25.83)	342.76 (24.63)	347.65 (24.41)
	Block 2	469.51 (29.81)	410.15 (27.64)	382.51 (23.20)	351.36 (27.39)

Appendix G: Composite tasks of domain scores

Attention Domain

1. Digit span forward (maximum number of digits): WMS-III
2. Spatial span forward (maximum number of digits): WMS-III

Memory Domain

1. CVLT-II: total trials 1-5 – raw score
2. CVLT-II: short delay free recall – raw score
3. CVLT II: long delay free recall – raw score

Language Domain

1. Phonemic COWAT (FAS): total score
2. Semantic COWAT: total score

Visuospatial Domain

1. Visual Form Discrimination: total number correct
2. DKEFs Trails – Visual Scanning: scaled score

Speed Domain

1. DKEFs Color-Word Interference – color naming: scaled score
2. DKEFs Color-Word Interference – word reading: scaled score
3. DKEFs Trails – Motor speed: scaled score

Executive Function Domain

1. DKEFs Color-Word Interference – contrast [Inhibition – color naming]: scaled score
2. DKEFs Color-Word Interference – contrast [Inhibition/Switch minus combined color naming/word reading]: scaled score
3. DKEFs Trails – contrast [Switching – combined number and letter sequence]: scaled score

Learning Domain

1. CVLT II: learning slope – raw score

Semantic Clustering Domain

1. Semantic COWAT – total score
2. CVLT II Semantic Cluster– raw score

Appendix H: Means and standard deviations of domain scores for each age group

Domain	**Age Groups**		
	Young	Mid-old	Old-old
Attention	.32 (.68)	-.24(.88)	-.28(.74)
Memory	.60(.80)	-.41(.86)	-.61(.48)
Language	-.12(.67)	.37(1.07)	-.25(1.01)
Visuospatial	-.22(.82)	.17(.57)	.19(.79)
Speed	-.20(.74)	.11(.76)	.23(.97)
Executive Function	-.12(.61)	.08(.91)	.33(.44)

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