

## CHAPTER 32

---

# ATTENTION AND AGEING

---

THEODORE P. ZANTO AND ADAM GAZZALEY

## INTRODUCTION

---

THE term ‘attention’ has been part of the English language for centuries, and the ‘state of giving heed’ has been recognized across cultures for millennia. The ubiquitous nature of this phenomenon has led to the notion that ‘[o]n attention itself, it is needless to discourse at length; its nature and conditions are familiar to every thoughtful student’ (Munsell 1873: 11), and more succinctly, ‘everyone knows what attention is’ (James 1890, vol. 1: 403). Yet James (1890) discusses different types of attention, just as other chapters in this volume show that attention is more multifaceted than is appreciated in common parlance. Thus, attention is a set of cognitive processes, and transcends a single definition or overarching theory (Parasuraman 1998). The goal of this chapter is to review the various aspects of attention in the context of how they change in normal ageing.

There are several critical reviews on ageing and attention (e.g. Hartley 1992; Kok 2000; McDowd and Shaw 2000; Rogers 2000), some within the last few years (Madden 2007; Kramer and Madden 2008; Drag and Bieliauskas 2010). However, as mentioned, there are many aspects of attention and thus many ways to consider how attention may be affected by ageing. Here, we will attempt to summarize and present a broad overview of the current state of attention and ageing research. The chapter is organized according to the following categories of attention: selective attention, sustained attention, divided attention, task-switching, and attentional capture. The final section will provide an overview of several current theories on cognitive ageing and specifically how they pertain to attention. Although the term ‘attention’ can be ambiguous, we will attempt to use it in context of specific processes with the understanding that lines drawn in the sand are influenced by the ocean’s tide. Throughout this chapter, several questions are revisited: Does ageing impact this particular aspect of attention? If so, what are the sources of attentional decline? Do deficits in performance reflect true changes in attention or are they a manifestation of other age-related changes, such as alterations in sensory or perceptual abilities, memory, or processing speed?

## SELECTIVE ATTENTION

---

Selective attention refers to goal-directed focus on task-relevant information while ignoring other irrelevant information. This section is subdivided according to the type of information that is selectively attended/ignored: spatial location, features, objects, intermodal information, time, and internally based items.

### Spatial

Spatial selective attention refers to allocating attention to one location while ignoring another. One of the most commonly used paradigms to assess spatial selective attention utilizes a central or a peripheral cue to indicate where a target will subsequently appear. The response-time difference between validly cued and invalid, neutral, or uncued targets serves to measure attentional orienting processes (Posner 1980). Whereas peripheral cues are thought to provoke reflexive shifts in spatial attention, central cues invoke both volitional and reflexive orienting (Ristic and Kingstone 2006; Olk et al. 2008). There has been an accumulation of evidence indicating that cue-based facilitation of attentional shift to a location is preserved in ageing (Nissen and Corkin 1985; Hartley et al. 1990; Gottlob and Madden 1998), regardless of whether the cue attracts attention automatically or wilfully (Tales et al. 2002). However, age-related declines in central cueing may be observed by diminishing the saliency of the cue, although this has been attributed to deficient sensory mechanisms in older adults and not to a decline in attentional shifting (Folk and Hoyer 1992). Thus, top-down control of spatial orienting may indeed be preserved in ageing. This is supported by neural evidence of the cue validity effect on the event-related potential (ERP) amplitude being unaffected by ageing, although older adults exhibited delayed early ERP components following target stimuli (i.e. P<sub>1</sub>, N<sub>1</sub>, Nd<sub>1</sub>), suggesting a decline in early sensory (bottom-up) processes (Yamaguchi et al. 1995; Curran et al. 2001; Lorenzo-Lopez et al. 2002). Related to this, there is evidence of additional recruitment of frontal (top-down) resources in older adults during a cued spatial selective attention task (Talsma et al. 2006), suggesting that top-down processes may compensate for declines in bottom-up function in order to retain performance.

Interestingly, younger adults show a leftward bias in visual-spatial tasks that dissipates in older adults (Barrett and Craver-Lemley 2008), potentially due to more distributed neural processing in ageing (Cabeza 2002). Along these lines, recent research has shown an age-related decline when attention is cued to the left visual field (Nagamatsu et al. 2011), suggesting that previous spatial cueing research may be oversimplified when averaging data from both visual fields. Furthermore, the age-based deficit observed in the left visual field may be attributed to both sensory (delayed P<sub>1</sub> of the ERP) and attentional processes (reduced anterior directing attentional negativity) (Nagamatsu et al. 2011). Incidentally, older adults with diminished attentional enhancement of the left

visual field are more likely to experience a fall (Nagamatsu et al. 2009). Taken together, cueing paradigms have historically shown that volitional shifts in spatial attention are preserved in older adults as long as bottom-up declines in sensory processes are controlled for, yet attentional declines specific to the left visual field may occur in normal ageing. Additional research is required to verify these recent findings.

Another way to assess spatial attention in the visual domain is through search tasks that require identifying a target in the presence of multiple non-target (distractor) items. The measure of search efficiency typically relies on response time (RT) for target detection. When the target differs from distractors in a particular feature (e.g. size, colour, shape), detection is highly efficient, as the target appears to 'pop-out' due to bottom-up influences that capture attention automatically. However, visual search becomes less efficient when the target shares some feature with the distractors, and this efficiency is also contingent on the number of distractors in the visual field (display size). Thus, top-down influences such as prior knowledge of the differences between the target and distractor are thought to play a prominent role in search detection when task difficulty increases via featural similarity and display size. When targets share similar features to the distractors (i.e. non-singletons), older adults are slower and less accurate in detecting non-singleton targets (McDowd and Shaw 2000; Hommel et al. 2004; Madden and Whiting 2004). However, it is unclear whether this reflects diminished top-down processes or is due to compensatory mechanisms being over-taxed in older adults so that they can no longer adjust for deficient bottom-up processes. Indeed, there are numerous age-related declines in sensory and perceptual processes that may contribute to slower and less accurate visual search (Schneider and Pichora-Fuller 2000; Salthouse and Madden 2007), and as such, additional reliance on top-down mechanisms in older adults may be necessary to compensate for a decline in bottom-up processes. Thus, more research will be required to control for age-related differences in bottom-up sensory processes in order to assess whether top-down attentional processes for visual search are retained in ageing.

Although the vast majority of ageing research in spatial selective attention has focused on the visual domain, there is some evidence for an age-related decline in spatial selective attention in the auditory domain. Although both younger and older groups demonstrated comparable benefits from a priori knowledge of a target sentence source (Singh et al. 2008), older adults exhibit a deficit in identifying target sentences in the presence of distractors that are presented from spatially distinct locations (Duquesnoy 1983; Singh et al. 2008). These results suggest an age-based decline in filtering auditory distraction from distinct spatial locations. Indeed, a binaural auditory cued attention task has identified ageing differences in ERP measures to cues and targets which was interpreted as signatures of an age-related decline in attentional regulation (Bennett et al. 2004). Again, it is possible that age-related differences in auditory spatial attention may be attributed to declines in sensory processing, such as sound segregation. In either case, ageing research on spatial selective attention in the auditory domain is limited and additional research is required to fully assess whether top-down attentional declines are present.

Overall, research in spatial selective attention suggests that once age-based general slowing and declines in bottom-up sensory processes are accounted for, this ability is largely preserved in ageing. However, a specific attentional decline to the left visual field may be present. Also, there exists the possibility that studies of spatial attention have not been challenging enough, and if the demands were increased, age-related effects may be apparent. For example, age-related changes in visual search appear when task difficulty is increased. Future research must delineate whether this represents a decline in top-down processes or a limitation in compensatory top-down processes to overcome bottom-up deficits.

## Feature-based

Selective attention to features typically refers to attending and ignoring elementary parts of a stimulus, such as colour or shape, or analogously, a tone in an auditory environment. A common paradigm used to assess feature selectivity and interference control is known as the Stroop task (Stroop 1935). Participants are required to report the colour of a word and not the word itself, which is the name of a different colour. For example, the word 'red' in blue ink would require a participant to say 'blue' and withhold the reflexive response to read and say the word 'red'. In general, older adults are slower than younger adults during the Stroop task (e.g. Comalli et al. 1962; Cohn et al. 1984; Klein et al. 1997), indicating a decline in interference control. Interestingly, an auditory version of the Stroop task shows similar age-related declines (Sommers and Danielson 1999; Sommers and Huff 2003). However, it has been argued that the Stroop task does not reflect a decline in selective attention per se, but rather, may reflect basic (or central) processing speed differences (Salthouse and Meinzig 1995; Earles et al. 1997; Verhaeghen and Cerella 2002). Yet others have attempted to account for generalized slowing and suggest an age-related decline in selective attention remains present (Hartley 1993; Spieler et al. 1996). Although more empirical and theoretical work may be required to resolve this conflict (McDowd and Shaw 2000), here, we will review other paradigms to assess age-related differences in feature-based selective attention.

Another common paradigm used to assess selective attention is negative priming, in which the target stimulus is either novel (control) or has been presented in the preceding trial as a distractor. The slowing in response times to targets that were previously used as a distractor measures the amount the distractor was inhibited and is referred to as negative priming. Younger adults display negative priming effects to visual features, which may be observed electrophysiologically as changes in early ERP signatures of feature processing (Nobre et al. 2006). However, there is conflicting evidence as to how the negative priming task affects older adults' ability to inhibit irrelevant features. Whereas early reports suggested an age-related decline in inhibition (Hasher et al. 1991; Tipper 1991; Connelly and Hasher 1993), subsequent research has concluded age-equivalence in feature-based negative priming effects (Sullivan et al. 1995; Schooler et al. 1997; Simone and McCormick 1999). Thus, it is unclear whether older adults exhibit differences in

inhibitory control during negative priming tasks for visual features. Interestingly, meta-analyses on negative priming tasks (not just for visual features) also disagree whether age-based inhibition differences exist. Although the meta-analyses agree that both younger and older adults display negative priming effects, one meta-analysis of 21 studies suggested older adults exhibited less of an effect (Verhaeghen and De Meersman 1998) whereas a later meta-analysis of 36 studies found no age differences (Gamboz et al. 2002). Due to this ambiguity, negative priming tasks for objects will not be discussed in the object-based selective attention section. We will turn to other ageing research on feature selection for more definite answers.

In a recent delayed recognition task for colour and motion features, older adults were observed to respond slower to features at the time of the memory probe, even after correcting for age-related declines in perceptual processing and general response slowing (Zanto et al. 2010b). Furthermore, ERP data indicated age-equivalence in early perceptual processes (at the P1), but older adults exhibited reduced amplitudes and processing delays at the stage of feature selection (selection negativity), which predicted subsequent response times. Although the behavioural responses assessed working memory performance, these results are similar to a previous discrimination task that reported an age-related decline in feature selective attention performance concomitant with a decrease in neural measures of feature selection (selection negativity) (Kenemans et al. 1995). A more recent report has corroborated these findings, such that when instructed to detect coherent motion from one of two superimposed random dot kinematograms (RDKs) that differ by colour, older adults perform equivalently to younger adults in motion detection, but are less reliable in discriminating the target from distractor motion (Quigley et al. 2010). Furthermore, Quigley and colleagues (2010) show that electroencephalography (EEG) frequency tagging of the steady-state visual evoked potential (SSVEP) was present in both age groups, but only modulated by attention in the young adults. This indicates that older adults exhibit declines in the attentional modulation of feature processing, which may not be attributed to sensory declines. Taken together, recent data indicate that age-related declines in feature-based selective attention may be manifest via reduced selectivity as well as processing speed delays.

Overall, there is much conflicting evidence on the effects of ageing in feature-based selective attention. Additional empirical or theoretical work will be required to account for these discrepancies. However, the current state of research would indicate that older adults exhibit a decline in visual attention to features based on processing speed delays and deficient neural modulation during feature selection. Additional research will be required to ascertain ageing differences in auditory-based feature selection.

## Object-based

Everyday visual items consist of objects that may differ in component features such as colour or shape. However, the visual system can process objects holistically, based on integrated features and not individual parts (Egley et al. 1994; Rodriguez et al. 2002). The

Flanker task (Eriksen and Eriksen 1974) has been a popular method to assess age-related differences in object-based selective attention. The task entails responding to a central object (e.g. letter or arrow) that is flanked by either congruent (e.g. >>>) or incongruent (e.g. <><) objects. The response-time difference between congruent and incongruent trials measures interference control. Although some research has indicated that older adults are more negatively impacted by incongruent distraction (Zeef and Kok 1993; Zeef et al. 1996; Colcombe et al. 2005), some researchers have observed no differences in ageing (Kramer et al. 1994; Falkenstein et al. 2001; Fernandez-Duque and Black 2006; Kamijo et al. 2009), and others have suggested younger adults are more negatively affected by flanker interference (Wright and Elias 1979; Madden and Gottlob 1997; Mathewson et al. 2005). As can be seen, flanker effects are highly variable, potentially due to variable proximity between the target and flankers and the nature of the objects. Age-related declines in flanker interference are lessened by increasing the target-flanker distance (Cerella 1985; Zeef et al. 1996), which has been attributed to peripheral acuity changes in older adults (Cerella 1985). This suggests that age-related declines in the Flanker task may be due to sensory deficits and not object-based selective attention. However, recent neuroimaging research has shown older adults display decreased prefrontal cortical activity concomitant with declines in flanker interference relative to younger adults (Colcombe et al. 2005; Samanez-Larkin et al. 2009), indicating selective attention mechanisms may be affected in ageing. Taken together, both bottom-up and top-down attentional mechanisms may drive ageing differences in the Flanker task. However, the results are mixed as to whether an age-related difference actually exists. Thus, additional paradigms will be reviewed to assess object-based selective attention changes in normal adults.

In delayed-recognition working memory tasks for faces and scenes, older adults exhibit diminished object recognition accuracy accompanied by a selective decline in suppressing the processing of irrelevant objects at multiple stages, as assessed using functional magnetic resonance imaging (fMRI) (Gazzaley et al. 2005) and comparing the amplitude and latency of ERP components (P1, N1, P3) (Gazzaley et al. 2008; Clapp and Gazzaley 2012). These ageing differences may be due to deficient prefrontal control mechanisms modulating activity at sensory cortices specific for the object category (Gazzaley et al., 2005, 2007), which include deficits in the modulation of sensory cortical activity prior to object onset, along with accompanying deficiencies in prefrontal-visual cortical functional connectivity, thus alluding to an age-related impairment in anticipatory processes (see temporal attention section for another example) (Bollinger et al., 2010, 2011). As such, an age-based suppression deficit exists even if older adults can predict the onset of the irrelevant object (Zanto et al. 2010a). Although the behavioural measure from these tasks was working memory performance, the age-related suppression deficit predicts subsequent memory accuracy indicating the source of the deficit is attentional in nature (Gazzaley et al. 2005). Interestingly, older adults' ability to suppress irrelevant objects is not abolished, rather it is limited exclusively to later processing stages (> 500 ms) (Gazzaley et al. 2008). It should be noted that this suppression deficit in ageing to faces was not replicated in a recent face-letter delayed recognition

task (Deiber et al. 2010), which seems likely due to differences in task demands. It has been shown that as task demands increase, neural measures of attended stimuli are enhanced while ignored stimuli are more suppressed (Rees et al. 1997; Handy et al. 2001; Rorden et al. 2008). Deiber et al. (2010) reported age-equivalence during letter recognition, but ceiling level accuracy scores for both age groups were observed. Thus, suppressing irrelevant face stimuli during the letter task may not have been necessary. Furthermore, Deiber et al. (2010) report an age-related decline in face recognition accuracy along with a suppression deficit (at the N170) to irrelevant letters, suggesting ageing differences in suppressing irrelevant information may become apparent in more difficult tasks. Additional recent research has lent support to the hypothesis that older adults exhibit declines in object-based selective attention exclusively under increased task demands (Schmitz et al. 2010). Taken together, it appears that older adults exhibit a deficit in visual selective attention specifically for ignoring irrelevant objects when the task is sufficiently challenging.

In the auditory domain, words may be considered objects because the individual letters (i.e. features) are not processed individually. There is a long history documenting a decrement in older adults' ability to understand speech in the presence of competing speech or distracting sounds (Carhart and Tillman 1970; Duquesnoy 1983; Li et al. 2004; Kim et al. 2007). This decline has been attributed to a combination of reduced auditory capabilities and slowed speed of processing in older adults (Van Rooij and Plomp 1991; Tun and Wingfield 1999). Interestingly, older adults may exhibit declines in auditory selective attention when the source of distraction is uncertain (Humes et al. 2006) and show an additional decline in attending to speech when the distracting speech is meaningful (Tun et al. 2002; Rossi-Katz and Arehart 2009), suggesting an influence of age-related changes in top-down processes. Furthermore, older adults exhibit deficits during selective dichotic listening (attend to one ear, ignore the other) (Gootjes et al. 2004; Hommet et al. 2010), which is exacerbated in the left ear (Alden et al. 1997; Hallgren et al. 2001), similar to the aforementioned age-based left hemifield declines in spatial selective attention for the visual domain. However, in recent studies assessing energetic (bottom-up, peripheral) and informational (top-down, cognitive) masking, the impact of meaningful distracting speech was age-equivalent (Helfer and Freyman 2008; Agus et al. 2009). Therefore, although bottom-up sensory processing may account for some deficiencies in selective attention to speech in the elderly, attentional declines in ageing may be present.

Overall, there is much conflicting evidence on the effects of ageing in object-based selective attention, similar to the accounts of feature-based selective attention using the Stroop and negative priming tasks. Additional empirical or theoretical work will be required to account for these discrepancies. It seems plausible that conflicting evidence in both the auditory and visual domain may stem from variable task difficulty. This should be addressed in future research. Nonetheless, the current state of research would indicate that older adults exhibit a decline in auditory object-based selective attention due (at least in part) to deficient bottom-up sensory processes, whereas visual deficits are exclusive to ignoring distraction when the task is difficult. However, as noted

for spatial attention (visual search), a distinction must be made to determine whether increased task difficulty reflects deficient top-down mechanisms as the basis or not enough top-down compensation to overcome bottom-up declines in ageing.

## Intermodal

The previous sections on selective attention reviewed studies where the attended and ignored stimuli were in the same modality. Although age-related declines in unimodal selective attention were reported, research in intermodal selective attention tends to indicate older adults retain their abilities to ignore distraction in a different modality. For example, both younger and older adults are equally affected by irrelevant background speech during a visual serial recall task (e.g. digits) (Beaman 2005; Bell and Buchner 2007), regardless of the type or intensity of the auditory distraction (Rouleau and Belleville 1996; Belleville et al. 2003). Furthermore, age-equivalence is retained on different visual tasks in the setting of auditory distraction, such as feature detection (Talsma et al., 2006: Experiment 2), verbal learning (Meijer et al. 2006), and star counting (Van Gerven et al. 2007). Although it is less explored, auditory selective attention also exhibits age-equivalence when distracting stimuli are in the visual modality. During auditory detection (Campbell et al. 2010), auditory word-pair memory tasks (Einstein et al. 2002), or auditory localization and categorization (Hugenschmidt et al. 2009), both younger and older adults were impacted by visual distraction to the same degree. Interestingly, performance may be enhanced with intermodal distraction and older adults may benefit more from multisensory information during detection (Peiffer et al. 2007; Diederich et al. 2008) and discrimination (Laurienti et al. 2006) tasks. Taken together, older adults appear unimpaired by distracting stimuli in a modality distinct from what is attended.

Neuroimaging data have lent some support to these intermodal findings in that both younger and older adults equally enhance neural activity in the sensory cortex of the attended modality while equally suppressing neural activity in the sensory cortex of the ignored modality (Peiffer et al. 2009). However, others have demonstrated an increased response in older adults' sensory cortex of the ignored modality along with increased prefrontal cortical activity (Townsend et al. 2006). Given that older adults did not display behavioural performance declines to the distracting stimuli, this suggests that age-related declines in suppressing irrelevant information may be compensated by recruiting additional attentional resources.

Recent research has used an auditory and visual n-back task with intermodal distraction to directly assess intermodal selective attention and ageing (Guerreiro and Van Gerven 2011). Interestingly, neither age group was negatively impacted by auditory distraction during the visual n-back task, while both age groups were affected by the visual distraction during the auditory n-back task. Importantly, older adults displayed a disproportionately larger impact from visual distraction. These results indicate that age-related distraction is modality-dependent such that suppressing intermodal

auditory distraction is relatively preserved whereas intermodal visual distractibility is impaired in normal ageing. The age-related decline to visual distraction during an auditory task is in contrast to results discussed above. However, very little ageing research has been conducted on this type of intermodal selective attention and so additional work must be done to explain these conflicting results.

In an impressive meta-analysis of 231 ageing experiments, Guerreiro et al. (2010) suggest that distraction in ageing is more likely to be observed in unimodal than intermodal paradigms, as well as when distraction is in the visual domain rather than auditory. Although conflicting results were observed, their conclusions were drawn based on the likelihood of occurrence. Additionally, they recognize the lack of intermodal paradigms for auditory attention with visual distraction, which may help resolve certain conflicts. Furthermore, it should be noted that this meta-analysis was not exclusive to selective attention paradigms, but incorporated many tasks that assess attentional capture (see below). Nonetheless, the current state of research on selective attention generally indicates that intermodal distraction is less impacted in ageing than unimodal distraction.

## Temporal

Attention may be allocated to specific points in time to optimize behavioural performance by forming expectations for the onset of an impending stimulus (Woodrow 1914). These expectations engage neural networks that encompass frontal, parietal, premotor, and sensory areas (Coull and Nobre 1998; Nobre et al. 2007). Electrophysiologically, posterior alpha and the contingent negative variation (CNV) may be enhanced prior to the expected stimulus (Miniussi et al. 1999; Praamstra et al. 2006) and the magnitude of this priming predicts subsequent perceptual processing and behavioural performance (Hillyard 1969; Ergenoglu et al. 2004; Hanslmayr et al. 2007). Interestingly, it has recently been shown that older adults do not utilize temporal cues to effectively allocate attentional processes in time, as compared to younger adults (Zanto et al. 2011). This was reflected by a lack of performance benefits and decreased neural signatures of expectation (CNV, alpha activity) when older participants were cued to when a target would appear. Importantly, Zanto and colleagues (2011) demonstrated that this age-based decline in allocating attention in time occurs for several types of tasks that vary in complexity, from simple detection to more complex discrimination and go/no-go tasks. Furthermore, Zanto and colleagues (2010a) also showed that older adults do not use temporal cues to enhance performance during a delayed working memory task. Together, these results indicate age-related declines in temporal based (anticipatory) attentional processes may be observed regardless of task difficulty. Recent neuroimaging research on expectation processes suggests that age-related declines in anticipation may stem from prefrontal cortex failing to prime sensory regions specific to the expected stimulus category (Bollinger et al. 2011).

In terms of timing abilities in general, older adults show greater variability in judging a timed interval (Block et al. 1998; Wild-Wall et al. 2009), less accuracy in producing intervals (Bherer et al. 2007; Gooch et al. 2009), and require slower tapping rates when producing syncopated movements (Stegemoller et al. 2009). Furthermore, older adults display deficits in the temporal ordering of sequential stimuli, which is contingent on individual speed of fluid reasoning, short-term memory, and attention (Ulbrich et al. 2009). Although it could be argued that timing abilities in older adults decline due to deficient automatic internal timing mechanisms, attention is thought to play an important role in timing tasks (Fortin 2003) and age-related declines in interval timing have been attributed to a reduction in attentional resources (reviewed in Lustig 2003; Balci et al. 2009). Neuroimaging data have supported this notion in that the source of age-based timing variability may stem from deficits in fronto-parietal attentional networks (Gunstad et al. 2006; Vallesi et al. 2009). Neurochemically, age-related timing deficits may reflect deficient dopaminergic and cholinergic inputs to time processing regions of the forebrain (Strong 1988; Wenk et al. 1989; Sarter and Bruno 2004), which may disrupt the encoding of temporal markers that help assess duration (Balci et al. 2009). Taken together, these results indicate that timing mechanisms are impacted as a result of attentional decline in normal ageing.

Overall, results from research on selective attention to time in older adults are fairly straightforward. Older adults exhibit declines in both expectation processes and timing functions that may be attributed to deficient fronto-parietal neural networks subserving attention. However, further research is required to determine whether the decrement in timing mechanisms is directly related to an age-related decline in temporal expectation processes.

## Internal

Internal attention refers to the focusing of attention on representations that are not present in the environment via refreshing working memory traces, recalling long-term memory, or self-generation, as in mental imagery. To assess internal selective attention, researchers have used measures of mental imagery performance. Older adults exhibit declines in image rotation and activation (accessing stored visual memory) while they retain the ability to compose (generating shapes) and scan visual mental images (Dror and Kosslyn 1994). Indeed, more recent research has confirmed that ageing selectively affects different aspects of imagery processes (De Beni et al. 2007). In a study assessing age differences in active and passive visual imagery, older adults exhibited declines in an imagery-based jigsaw puzzle (active), whereas no age differences were observed in composing visual mental images (passive) (Vecchi and Cornoldi 1999), similar to previous reports. In a different set of tasks designed to explore imagery and ageing, Craik and Dirks (1992) report age-related declines in the clock test (determine angle of clock hands), the Brooks letter test (give walking direction around the outside edge of a letter), as well as the east–west test (receive walking directions (e.g. right, left, right, back) and report direction they face (e.g. north)). The age-related decline in image activation has

been attributed to inhibitory mechanisms, speed of processing, and working memory (Bruyer and Scailquin 2000). Interestingly, although older adults may not perform as well as younger adults on imagery performance, prior occupational experience may reduce this discrepancy when the profession requires imagery-based attentional allocation (e.g. graphic designers) (Lindenberger et al. 1992).

Neuroimaging data have shown that visual imagery elicits neural activity in sensory cortical regions specific for the imagined item (e.g. FFA for faces, V5 for motion) (Kosslyn et al. 1999; O'Craven and Kanwisher 2000). This imagery-evoked activity in sensory cortex is thought to be under top-down attentional influences from the prefrontal cortex (Kosslyn et al. 1997) via functional connectivity (Mechelli et al. 2004). It has been suggested that age-related declines in mental imagery may stem from shrinkage of the prefrontal cortex (Raz et al. 1999). Indeed, recent research has shown an age-related decline in the selectivity of representations during imagery as well as changes in selectivity of prefrontal networks functionally connected to visual cortical regions involved in imagery (Kalkstein et al. 2011). These data indicate that age-related declines in mental imagery may stem from a loss of neural selectivity for imagined items in fronto-posterior networks.

It could be argued that many mental imagery tasks involve assessing memory and other executive functions in addition to internal selective attention. Another means to evaluate internal selective attention is via measuring activity of brain regions in a 'default network' that is preferentially active during self-referential thoughts (Gusnard et al. 2001) and mind wandering (Mason et al. 2007). This network consists largely of cortical midline structures such as the medial prefrontal cortex, anterior cingulate, and posterior cingulate cortex (Northoff et al. 2006). Of current interest, older adults display declines in activity (Koch et al. 2010) and connectivity (Grady et al. 2010) within the default mode network. Furthermore, older adults do not disengage the default network during cognitive tasks as much as younger adults (Lustig et al. 2003), and these age-based differences become more pronounced with increased task difficulty, which enhances the magnitude of this deactivation in younger (but not older) adults (Persson et al. 2007). Moreover, decreased default mode activity during rest predicts declines in attention, processing speed, and executive function in ageing (Damoiseaux et al. 2008) as well as decreased memory performance (Sambataro et al. 2010).

Overall, the current data support the notion of an age-related decline in internally based selective attention due to impaired prefrontal attentional control. However, some mental imagery tasks may be preserved in age, such as composing and scanning mental images. Nonetheless, additional research will be required to fully dissociate attentional from memory and other executive functions that may underlie the observed ageing deficits.

## Summary of selective attention in ageing

Although a general slowing of information processing (Salthouse 2000; Glisky 2007), as well as declines in bottom-up sensory processes may account for many age-related

changes, deficits in selective attention do appear to exist in several domains: feature selection, object-based attention, temporal attention, and some imagery abilities. Furthermore, age-related declines in spatial search appear to be attributable to deficits in selective attention, yet it is unclear whether this reflects deficient top-down mechanisms or insufficient compensation to overcome bottom-up declines. However, there is accumulating evidence that the ability to orient attention in space, ignore intermodal distraction, and execute other imagery tasks appears to be relatively unaffected by age. Additional research is required to assess whether deficits become apparent in these aspects of attention if task difficulty is increased, as well as fully delineate declines in selective attention from other cognitive processes and bottom-up effects.

## SUSTAINED ATTENTION

---

Sustained attention refers to the ability to maintain vigilance over time and is considered a basic attentional process (Drag and Bieliauskas 2010). Two reviews on sustained attention and ageing both report conflicting results within the literature, hindering a definitive conclusion (Davies and Parasuraman 1982; Giambra 1993). Recent research has shown that older adults perform comparably to younger adults on a classic test of sustained attention, the sustained attention to response task (SART), which requires a response to standard digits (e.g. 1–9; GO trials) and withholding a response when a rare digit appears (e.g. 3; NOGO trials) (Carriere et al. 2010). Similar results have been observed using the same basic task, except requiring responses only for rare targets (Berardi et al. 2001). However, it has been suggested that sustained attention is retained in adults aged 50–69 years but that deficits appear in adults older than 70 years of age (Filley and Cullum 1994). The aforementioned SART studies reported age-equivalence assessed only in older adults in the younger age category (i.e. 50–69 years). Indeed, changes in visual sustained attention appear as a function of age and are most prevalent in the more advanced age groups (Parasuraman and Giambra 1991; Mani et al. 2005). Interestingly, older adults that are not physically fit tend to display the largest decline in sustained attentional processes (Bunce et al. 1993), although this fitness-based attention deficit in ageing may be related (at least in part) to slowed processing speed (Bunce et al. 1996).

Using Parasuraman and Giambra's (1991) 30-minute target detection paradigm with a large sample size (~400 subjects), Giambra (1997) did not replicate their previous findings, but rather showed a modest ageing effect when non-sustained attentional aspects were minimized. Furthermore, ageing differences in sustained attention have been reported under increased perceptual demands, while age-equivalence may be observed with decreased task difficulty (Parasuraman et al. 1989; Mouloua and Parasuraman 1995). Thus, conflicting reports of an age-related decline in sustained attention may be attributed to differences in task difficulty, age and fitness of the subjects being assessed, or other non-sustained attentional processes.

Neuroimaging data from older adults have indicated a fronto-parietal network of regions recruited during a sustained attention task (Johannsen et al. 1997). During an auditory delayed-match-to-sample task, older adults' working memory performance is impaired by the presence an auditory distraction during the delay at long (i.e. > 9 sec) but not short (i.e. < 9 sec) intervals (Chao and Knight 1997). This suggests an age-related decline in sustained attention in the auditory domain, although this is difficult to distinguish from a decline in maintaining information in working memory and/or an inhibition deficit. Electrophysiologically, older adults (unlike younger) did not suppress activity in the primary auditory cortex to distracting tones during long delays (measured by Pa of the mid-latency auditory evoked potential), which predicted declines in behavioural measures of frontal lobe functioning (Wisconsin card sorting test). Furthermore, an age-based deficit was observed in prefrontal cortex function (less sustained frontal negativity). Thus, declines in sustained attention may result from the prefrontal cortex failing to suppress distraction-related neural processing in sensory cortex over time.

Overall, little research has been conducted to directly assess sustained attention abilities in older adults. Currently, it appears that sustained attention abilities are affected in ageing, although it may be contingent on task difficulty and the onset of this decline may be years later than other forms of attentional deficits. Nonetheless, additional research will be required to confirm the presence of an age-based change in sustained attention that is distinct from other non-sustained attentional processes and generalized slowing.

## DIVIDED ATTENTION

---

Divided attention tasks require participants to perform two or more tasks or process two or more sources of information concurrently. To assess the cost of dividing attention, performance under dual task conditions are often compared to performance when the tasks are performed separately. Here, we will discuss three types of divided attention in ageing: (1) multistream (allocating attention to multiple pieces of information in the same modality), (2) multimodal (allocating attention to multiple pieces of information in different modalities), and (3) multitasking (performing multiple tasks simultaneously).

### Multistream

Multistream divided attention refers to attention that is oriented towards multiple items that are simultaneously presented in the same modality with one task goal. Older adults perform equivalently to younger adults in the ability to divide attention across a visual display requiring multiple target detection (Somberg and Salthouse 1982) or target comparison (Hahn and Kramer 1995). However, if both letters and numbers are utilized as

targets, an age-related decline in performance is observed with increasing task difficulty (Salthouse et al. 1984), which may explain the conflicting results. Similarly, when tracking multiple objects in the visual domain, older adults become less accurate with an increasing number of tracked items (Tsang and Shaner 1998; Trick et al. 2005). Additionally, these age-related deficits increase with a longer duration of tracking or increased rate of motion (Sekuler et al. 2008). Importantly, Sekuler et al. (2008) provide evidence that these changes in multistream tracking are not due to an age-related deficit in working memory capacity.

In the auditory domain, older adults also exhibit declines in attending to multiple auditory streams (Wild-Wall and Falkenstein 2010), which is more prominent with increased task difficulty (Wilson and Jaffe 1996). Moreover, these declines may not be fully attributed to bottom-up deficits in auditory processing (Humes et al. 2006). Interestingly, both younger and older adults exhibit a right ear advantage during dichotic listening; however, there is a selective decline in the abilities of older adults to attend to their left ear during these divided attention tasks (Johnson et al. 1979; Martin and Jerger 2005; Andersson et al. 2008). Although white-matter hyperintensities are thought to play a role in this asymmetry (Gootjes et al. 2007), it more likely reflects a breakdown in fronto-parietal attentional networks that subserve inhibitory control (i.e. discriminate between lexical competitors) and disengagement processes (Sommers 1996; Bouma and Gootjes 2011). These results are similar to those reporting a deficit in orienting attention to the left visual field, which would suggest general declines in the right hemisphere of the aged brain.

Taken together, age-related declines in multistream divided attention are apparent with sufficient task difficulty. Interestingly, both younger and older adults are equally affected by distracting stimuli in the unattended visual field during visual tracking (Stormer et al. 2011). This provides additional evidence that certain aspects of spatial selective attention are retained in normal ageing, and of current interest, indicates that declines in divided spatial attention may not be attributed to deficits in spatial selective attention, although both forms of attention may be susceptible to some left hemifield neglect.

## Multimodal

Multimodal divided attention refers to attention that is oriented towards multiple items that are simultaneously presented in different modalities, but the task remains the same. In an audio-visual detection task, an age-related decline in performance was exhibited when attention was divided across modalities, but interestingly diminished following a 10-week aerobic exercise regimen (Hawkins et al. 1992). This benefit was observed only during multimodal divided attention (not focused attention to a single modality), indicating that enhanced cerebrovascular function may increase attentional capacity, but not efficiency in terms of speed. Similar research on the effects of aerobic exercise and ageing during multimodal divided attention did not observe such benefits of exercise (Madden et al. 1989). However, Hawkins et al. (1992) assessed divided attention via two

simultaneous discrimination tasks with each trial presented in rapid succession, whereas Madden et al. (1989) implemented a self-paced dual task (multitasking; see next section) with a priority for one task over the other. Thus, aerobic-related improvements in older adults' multimodal divided attention may be observed when it is under high demand, similar to how age-related declines are most prominent with increased task difficulty.

## Multitasking

Although multitasking can include multistream or multimodal divided attention, it is typically more cognitively demanding, as it requires attention to be allocated to multiple task goals as well as several stimuli. When attending to both auditory and visual stimuli with different task goals (e.g. detect auditory words denoting living things while categorizing visually displayed alphanumeric characters), older adults' performance declines with increasing difficulty (multimodal multitasking) (McDowd and Craik 1988), similar to reports from multistream divided attention research (Salthouse et al. 1984). Additionally, recent research using visual multistream multitasking has provided evidence of an age-related decline in dividing attention across detection and identification tasks (Mapstone et al. 2008), mental image rotation (Plankin task) and tracking, as well as memory recognition (Sternberg task) and tracking (Tsang and Shaner 1998). Tsang and Shaner (1998) attributed this divided attention deficit in ageing to reduced processing efficiency, which could be attributed to generalized slowing, and not a decline specific to the attentional domain. Similarly, data from psychological refractory period experiments indicate that older (relative to younger) adults are slower to respond to a second task when the stimulus onset asynchrony between tasks decreases (Allen et al. 1998; Glass et al. 2000). This provides additional evidence that generalized slowing may account for some age-related changes in multitasking.

In the auditory domain, older adults exhibit declines comparable to younger adults in multistream multitasking, such as with competing speech signals during concurrent target detection and voice counting tasks (Helfer et al. 2010). However, age-related declines became apparent when the task became more complex via informational masking as well as spatial segregation of the sound sources. This indicates that in addition to generalized slowing, attentional resources may also contribute to age-based deficits in multitasking. Importantly, a meta-analysis of multitasking in ageing has suggested that once generalized slowing is accounted for, an additional decline persists in older adults (Verhaeghen et al. 2003), which extends earlier sentiments from another review on age-based reductions in multitasking abilities (Kramer and Larish 1996). Thus, age-based differences in multitasking may not be solely attributed to generalized slowing, but to declines in attentional mechanisms as well. Moreover, it should be noted that some declines in multitasking may also be attributed to task-switching (Hartley and Little 1999) or task coordination strategy (Glass et al. 2000). Given the complexity of multitasking, it is not surprising that multiple cognitive sources may underlie an age-based decline during divided attention tasks.

Whereas standing and walking are often considered automatic motor activity with negligible cognitive requirements, previous research has indicated that they utilize spatial attention resources (Kerr et al. 1985) from fronto-posterior neural networks (Malouin et al. 2003). As such, performing a cognitive task while standing or walking may be considered multitasking. Indeed, similar to other forms of multitasking, older adults exhibit a decline in postural control and gait when performing a variety of cognitive tasks and these declines are contingent on the type and complexity of the task (reviewed in Woollacott and Shumway-Cook 2002). Berger and Bernard-Demanze (2011) suggest that older adults prioritize posture stability whereas younger adults incorporate a 'cognition first' principle during multitasking. A recent review on attention and gait has indicated that older adults may reduce gait speed or decrease response times to the cognitive task in order to retain gait stability (Yogev-Seligmann et al. 2008). Similarly, during a mobile phone conversation, older adults require more time to cross a street relative to younger adults, suggesting impairments in cognitive planning processes and divided attention (Neider et al. 2011). Together, these results indicate that age-related declines in attention may not only result in reduced cognitive performance, but may increase the risk for falling and personal injury (Sheridan and Hausdorff 2007).

In a recent multistream multitask study requiring tracking and target detection, older adults exhibited a decline in dual-task performance that was more pronounced when a motor response was required while multitasking (Wild-Wall et al. 2011). This result corroborates data from posture and gait multitasking experiments to suggest that motor activity usurps attentional resources, which has strong implications for driving performance in the elderly (Keskinen et al. 1998; Hahn et al. 2010). Neurally, Wild-Wall et al. (2011) provide electrophysiological evidence that older adults recruit additional processing resources during multitasking as indexed by an enhanced CNV. Moreover, this additional neural recruitment in older adults may reflect fronto-parietal compensatory mechanisms in order to retain multitasking abilities (Fernandes et al. 2006; Hartley et al. 2011).

In a recent experiment, older adults displayed a working memory performance deficit relative to younger adults when presented with distracting information (Clapp and Gazzaley 2012), similar to previous reports of a suppression deficit for object-based selective attention. Of current interest, Clapp and Gazzaley (2012) also showed that older adults exhibited an even greater working memory performance decline relative to younger adults when multitasking was required, i.e. discrimination task during the working memory maintenance period. Moreover, using the N170 latency of the ERP as an indicator of visual attention, age-based decrements in selective attention and multitasking in the setting of a working memory task arise from different attentional processing stages: selective attention differences (i.e. distractibility) are driven by over-allocation of attention to distractors in early visual processing stages, whereas multitasking declines are not due to excessive attention by older adults to the secondary task/stimuli, but rather arise from age-related changes at other processing stages. In support of this finding, fMRI data confirmed that older adults do not allocate more attention to interrupting stimuli during a working memory maintenance period than younger adults. Task-based functional connectivity analysis extended the finding by

revealing that older adults fail to disengage neural networks associated with the interrupting task and fail to re-establish functional connections of the neural networks subserving the initial memory task (Clapp et al. 2011).

Fortunately, there is evidence that age-related declines in multitasking are not absolute. Tsang and Shaner (1998) reported that previous occupation lessened the impact of multitasking in older adults when the task was domain-specific to prior experience. Moreover, dual-task training can help alleviate some age-related declines in multitasking by enhancing attentional control (Bherer et al. 2005, 2006), which can generalize to new task combinations and stimuli (Bherer et al. 2008). Furthermore, multitasking training may improve multiple cognitive domains that invoke attentional processes such as task-switching, working memory, and reasoning (Basak et al. 2008). These improvements via training have been linked to neural plasticity in older adults' prefrontal cortex to yield more asymmetric activations similar to younger adults (Erickson et al. 2007).

## Summary of divided attention in ageing

In general, divided attention tasks yield significant age-related declines in performance, particularly when tasks are complex. It is possible that the division of attention may simply act to increase the overall complexity of the task, which necessitates the involvement of more mental operations. These findings are typically explained in terms of declining processing resources in normal ageing, which are over-extended in older adults when attention must be divided between two or more sources (Glisky 2007). Importantly, declines in attentional processes may increase the risk in older adults for personal injury when performing a cognitive task while they are executing motor behaviours such as walking or driving.

## TASK-SWITCHING

---

Similar to divided attention, task-switching is the ability to switch rapidly among different skills, tasks, or cognitive sets. Older adults' performance is slower than younger adults when attention must be switched from one task to another, requiring a global change of the cognitive set, and less so (if at all) during local task-switching (where both mental task sets are active) (Mayr and Liebscher 2001; Verhaeghen and Cerella 2002; Wasylyshyn et al. 2011). It has been suggested that age-based changes in task-switching may be due to perceptual processing slowing (Salthouse et al. 2000). Recently, it has been argued that age-related deficits in task-switching occur at the stage of maintaining representations outside the focus of attention, whereas age-equivalence may be observed when switching representations into and out of the focus of attention (Dorbath and Titz 2011). However, this more likely reflects age-equivalence during local task-switching. Although

age-related declines in memory may account for some task-switching effects (Kramer et al. 1999a; Kray and Lindenberger 2000), global task-switching deficits in ageing may also be attributed to attentional changes as they may be observed in the absence of a memory component (e.g. Cepeda et al. 2001; Kray et al. 2002). Furthermore, research has shown that older adults may minimize task-switching declines when the need to switch tasks is predictable (Mayr and Kliegl 2000; Kray 2006; Coubard et al. 2011). Together, this may be interpreted as providing evidence for general slowing in older adults and/or an inability to disengage attention from one task and refocus attention on another task (Hartley and Little 1999; Clapp et al. 2011).

Interestingly, during a rapid sequential audio-to-visual detection task, an age-related decline in attentional switching performance was reduced following a 10-week aerobic exercise regimen (Hawkins et al. 1992). This benefit was only observed when switching between modalities (not the within modality task), indicating that enhanced cerebrovascular function may increase attentional orienting, but not a general increase in detection speed efficiency. However, in a recent training study specific for task-switching, older adults do not benefit as much as younger adults suggesting trainability for switching is reduced in older adults (Dorbath et al. 2011).

Task-switching is thought to rely on control processes related to executive functioning. It has been associated with activity in areas subserving attention such as prefrontal (Rushworth et al. 2002) and parietal (Kimberg et al. 2000) cortex, particularly in the left hemisphere of the prefrontal cortex (Rogers et al. 1998; Braver et al. 2003). Age-related declines in task-switching have been attributed to decreased functional connectivity in fronto-parietal neural networks (Madden et al. 2010). Moreover, older adults display decreased fronto-central slow waves of the EEG, which may index declines in the maintenance of task-set information (Adrover-Roig and Barcelo 2010) or a failure to fully implement the task set (West and Travers 2008). However, frontal declines have also been observed during local task-switching without an age-based switching cost (Hampshire et al. 2008). Despite recent reports of decreased frontal activity in older adults during task-switching, when switching between a discrete processing task and an ongoing working memory task, high performing younger adults do not utilize prefrontal regions, whereas older adults and low performing younger adults recruit prefrontal regions (Smith et al. 2001). Similar to other aspects of attentional decline, older adults may recruit additional frontal regions to potentially offset age-based deficits in task-switching (DiGirolamo et al. 2001; Goffaux et al. 2008).

Overall, age-related declines may be observed when switching between tasks that require a global shift in the cognitive set. However, age-equivalence is often observed when both task sets are actively maintained or well practised (Bojko et al. 2004). Older adults may exhibit additional neural activity in the prefrontal cortex to retain performance abilities, but these compensatory mechanisms are insufficient for more dramatic shifts in attention, as in global task-switching. Although exercise and cognitive training may alleviate some of these switching declines, training may not be as effective in ageing as in youth.

## ATTENTIONAL CAPTURE

---

Here, we refer to attentional capture as the automatic or reflexive orienting of attention due to a (often unexpected) stimulus. Top-down attentional processes may minimize or inhibit stimulus-driven attentional capture (e.g. Bacon and Egeth 1994) and the ability to do so is arguably the most experimentally tested phenomena in attention and ageing research. One of the most basic assessments of attentional capture is the Simon task, where a single item is presented in one of two locations (left or right) and participants must respond with a left or right key press that is contingent on the stimulus location or feature. Response times (RTs) are speeded when the stimulus and response location are congruent (e.g. both on the right) relative to incongruent trials (i.e. when response must be on the opposite side relative to stimulus location), and this result is observed regardless of whether participants respond to spatial (Simon 1969) or non-spatial features of the stimulus (Craft and Simon 1970), whether the stimulus is auditory, visual, or somatosensory (Simon et al. 1971; Hasbroucq and Guiard 1992), or whether the participant responds with their hand, foot, or eyes (Leuthold and Schroter 2006). The difference in RTs between congruent and incongruent trials serves to measure inhibitory control of the prepotent stimulus–response mapping.

During the Simon task, older adults exhibit a disproportionately larger impairment in RT on incongruent trials compared to younger adults in both auditory and visual domains (Pick and Proctor 1999; Juncos-Rabadan et al. 2008; Vu and Proctor 2008), even after correcting for general slowing in the older population (Van der Lubbe and Verleger 2002; Castel et al. 2007). However, bilingual older adults show less of a decline than monolingual older adults during both a simple and complex (i.e. requiring working memory) Simon task (Bialystok et al. 2004), suggesting that inhibitory control of the prepotent response is better retained in age when linguistic control of multiple languages is utilized across the lifespan. However, this advantage was only replicated during the simple Simon task, and not when the task difficulty is increased by an additional working memory component (Rosselli and Salvatierra 2011). Interestingly, the age-related decline during the Simon task may be eliminated by introducing a third ‘no-go’ option that requires participants to respond left, right, or withhold the response (Kawai and Kubo-Kawai 2010). Although it is unclear how response inhibition interacts with the prepotent stimulus–response mapping, this finding suggests a dissociation between these processes that may be differentially affected by normal ageing.

EEG data during the Simon task have shown age-related differences in the relationship between the amplitudes of the posterior contralateral negativity (i.e. N2pc) and the early lateralized readiness potential (Van der Lubbe and Verleger 2002). These data indicate that neural network activity between posterior and motor cortex may be affected by age, which results in a decline of inhibitory processes that control visuomotor transmission. Source localization of magnetoencephalography (MEG) during the Simon task indicates that the advantage observed in bilingual adults stems from increased reliance

on left hemisphere fronto-temporal regions suggesting systematic changes in frontal executive functions (Bialystok et al. 2005). Thus, research from the Simon task shows an age-related decline in inhibiting the prepotent response, which may be partially retained in bilingual older adults so long as task difficulty remains minimal.

Although older adults display declines in the Simon task to irrelevant spatial information, no such declines are observed in an accessory-stimulus version of the Simon task (Simon and Pouraghabagher 1978; Proctor et al. 2005). In these experiments, participants made left or right button responses based on a relevant visual stimulus presented centrally which was accompanied by an irrelevant auditory tone to the left or right ear. These results suggest that age-related differences elicited by the Simon task may be driven by single stimuli that convey more than one type of information which overload processing resources, while older adults retain their ability to ignore spatial information from another modality. These findings are similar to the age-equivalence reported during intermodal selective attention paradigms.

Similar to the Simon task, peripheral cues reflexively orient attention to the cued location. Although spatial cueing paradigms do not typically elicit age-related differences in reflexive (peripherally cued) or volitional (centrally cued) attention, several exceptions have been noted. Older adults do not benefit as much as younger adults to central cues when a peripheral cue is presented simultaneously (Brodeur and Enns 1997) or in rapid succession (Iarocci et al. 2009). This suggests that control over attentional capture declines in normal ageing. Furthermore, although the time course of cued facilitation is comparable between younger and older adults following central cues (Folk and Hoyer 1992; Lincourt et al. 1997), age-related differences are evident during peripheral cueing paradigms such that older adults exhibit prolonged facilitation at short cue-target intervals (e.g. 50–200 ms) and a delayed inhibition of return (slowed RT to cued location after attention shifts back from periphery to centre) at longer intervals (Brodeur and Enns 1997; Lincourt et al. 1997; Castel et al. 2003), even after correcting for age-related slowing (McLaughlin et al. 2010). This suggests that older adults have greater difficulty disengaging from spatial cues that reflexively orient attention (Castel et al. 2003; Langley et al. 2011). ERP data have supported this notion by showing an age-related absence of an N2 (reflecting control or inhibition) following a peripheral (reflexive) cue and instead displaying a P3b (reflecting processing of information) (Wascher et al. 2011).

During visual search paradigms, if a target differs from distractors in a particular feature (e.g. size, colour, shape), detection is highly efficient, as the target appears to 'pop-out' due to bottom-up influences that capture attention automatically. When older adults are presented with targets whose features differ from distractors (singleton), age-equivalence may be observed when ignoring a singleton distractor (Theeuwes et al. 1998; Kramer et al. 1999b; Colcombe et al. 2003). Yet others have shown an age-related decline when attempting to inhibit an irrelevant singleton (Pratt and Bellomo 1999; Experiment 3; Whiting et al. 2005) and are slower to disengage once attention has been captured (Juola et al. 2000). These conflicting results may be due to differences in the singleton used (Pratt and Bellomo 1999) or task difficulty, as older adults show greater declines in ignoring distraction when the singleton is more salient (Kramer et al.

2000). Interestingly, a general age-based RT slowing to target singletons is observed that is not contingent on display size (Plude and Doussard-Roosevelt 1989; Whiting et al. 2005). This indicates that although perceptual processing and/or motor execution mechanisms are slowed in older adults, there is some preservation of bottom-up processes that facilitate highly efficient search.

Whereas detection of target singletons may be driven by bottom-up processes, top-down knowledge of the target feature may help to reduce or eliminate the effects of distraction (Leber and Egeth 2006). Indeed, older adults may display similar benefits as younger adults in utilizing top-down processes to enhance the detection of target singletons (Madden et al. 2004; Whiting et al. 2005; Costello et al. 2010), suggesting some control of attentional capture is retained in ageing. However, when the task requires greater attentional demand, older adults do not benefit as much as younger adults in utilizing top-down processes against attentional capture (Whiting et al. 2007). Moreover, when features of a target singleton or distractors vary on a trial-to-trial basis, older adults do not benefit as much as younger adults from prior knowledge of the target (Madden et al. 2005, 2007a). This may be due to age-related declines in switching their cognitive set (see section on task-switching), or potentially indicating that older adults may rely more heavily on top-down attention to target features in order to compensate for slowed bottom-up processes.

Neuroimaging research has lent some support for this top-down hypothesis, indicating that older adults utilize prefrontal cortical regions during target singleton detection whereas younger adults recruit posterior visual processing areas (Madden et al. 2007b). However, others have shown a similar age-based shift in posterior to frontal recruitment in singleton detection concomitant with age-related declines in accuracy, suggesting these attentional processes are vulnerable in ageing (Lorenzo-Lopez et al. 2008b). Furthermore, the N2pc of the ERP (a neural correlate of target selection) is attenuated and slowed in older adults during singleton detection, which may indicate a reduction in attentional resources in normal ageing that occurs later than the capture of attention *per se* (Lorenzo-Lopez et al. 2008a).

Another popular method to assess attentional capture is through oddball tasks where a standard stimulus is presented many times and infrequent oddball (target) stimuli occur randomly throughout the task to capture attention. In general, older adults exhibit reduced ERPs (mismatch negativity, P3, N400) to oddball stimuli in both the auditory and visual modalities (reviewed in Kok 2000). This was interpreted as a decline in the efficiency of detecting deviant stimuli from common background information. During a bi-field visual selective attention task where participants were required to detect infrequent targets (oddballs) in one hemifield (and ignore the other hemifield), older adults retained detection accuracy, but committed more false alarms than younger adults (Solbakk et al. 2008). False alarms were observed primarily in the attended hemifield, so age-related differences in this task may be due to difficulties in stimulus discrimination and/or inhibitory control of erroneous responses. Interestingly, the extent of neural activations measured by fMRI predicted behavioural performance in both groups; however, the locus of this activity differed such that

younger adults utilized posterior regions whereas older adults relied on frontal areas. These results are similar to target singleton search paradigms in that older adults shift processing resources from relatively automatic posterior regions to more controlled functioning via frontal areas.

Overall, these results indicate that older adults show deficits in suppressing reflexive attentional capture as well as difficulty disengaging their attentional resources once it has been captured. Although some aspects of capture may be retained in age, top-down control of these prepotent responses tends to decline with increasing task difficulty. Moreover, older adults rely more heavily on prefrontal neural regions during control of attentional capture. Future research will be required to assess whether this reflects deficient top-down processes or insufficient compensatory mechanisms to account for declines in bottom-up processing.

## THEORIES OF COGNITIVE AGEING

---

Although many theories on cognitive ageing focus on changes in multiple cognitive domains, they provide an important framework by which alterations in attention as we age may be understood. One of the most common findings in ageing research is that older adults are slower to respond to target stimuli. Additionally, as discussed above, there are also age-related delays in neural processing. These measures of slowing may not be attributed to any specific type of processing delay such as sensory or higher functions, but rather, appear pervasive throughout all stages of cognitive performance (Salthouse 1985; Birren and Fisher 1995; Salthouse 1996). Indeed, this slowing may be associated with age-based decline in the structural integrity of white-matter tracts (Rabbitt et al. 2007a; Turken et al. 2008) as well as loss of brain volume (Rabbitt et al. 2007b). As such, it has been proposed that age-related cognitive differences are due to a generalized slowing that results in less computational processing being completed in a set amount of time, which leads to less available information for higher-level functions (Salthouse 1996; Salthouse and Madden 2007). Importantly, as mentioned throughout this chapter, many examples of attentional decline may be accounted for by generalized slowing. Yet even after controlling for generalized slowing, age-related declines in attention persist, such as during inhibitory control.

Age-related declines in memory have been attributed to deficient inhibition processes that influence multiple cognitive functions (Hasher and Zacks 1988; Hasher et al. 1999). In this framework, working memory serves as the focus of attention, while inhibitory processes act as a central control mechanism to deny irrelevant information access, delete no longer relevant information, and restrain prepotent responses (Hasher et al. 2007). The inhibitory deficit view has been able to explain a wide array of age-related cognitive decline such as that documented in working memory (attentional focus), learning, and comprehension. Recent research has provided evidence linking age-related inhibitory deficits with processing speed declines, such that ERP latencies

that index age-based slowing were altered in a manner selective to the suppression of irrelevant information (Gazzaley et al. 2008). Thus, measures of neural processing speed and inhibition were shown to interact during early stages of visual processing and neural slowing may result in a failure to suppress irrelevant information leading to a working memory impairment.

A load theory proposed by Lavie and colleagues (Lavie and Tsai 1994; Lavie et al. 2004) suggests that ignoring irrelevant information only becomes necessary once attentional demands to relevant items reach a capacity limit. Thus, load theory agrees with the inhibitory view in attributing a source of an age-based decline in selective attention to ignoring distraction (Maylor and Lavie 1998). Interestingly, it was proposed that increased perceptual load and increased cognitive load (e.g. working memory, task-switching) have opposing effects on how distracting information is processed such that low perceptual load or high cognitive load result in increased distraction by irrelevant items (Lavie et al. 2004). Thus, under load theory, age-related declines in selective attention may be attributed to both perceptual and cognitive load capacity limitations. Yet others have suggested that age differences in selective attention may not be fully attributable to capacity limitations (Madden and Langley 2003; Kramer and Madden 2008).

Another theory attributes frontal lobe impairment to age-related declines in inhibition processes (Dempster 1992). This work was later expanded to relate prefrontal cortex dysfunction to an array of cognitive deficits, such as impairments in prospective memory, retrospective memory, interference control, and inhibiting prepotent responses (West 1996). This frontal lobe hypothesis has been successful in describing age-based changes during multiple task paradigms due to the role of the frontal lobe in executive functions. Thus, the frontal lobe hypothesis predicts increased distractibility in older adults because age-related declines in memory and attention to the task structure result in deficient selectivity for a target (Wecker et al. 2000; West and Bowry 2005). Indeed, much research has attributed attentional decline in ageing to changes in the prefrontal cortex and as such, many subsequent theories have been formed.

The use of context has been suggested to be a fundamental mechanism that changes in age, which results in attentional differences (Braver et al. 2001; Braver and Barch 2002). Here, context refers to the internal representations of task-relevant information that biases neural pathways responsible for task performance. Simulations of the context model have accurately predicted age-related changes in response times and inhibitory control (Braver et al. 2001), and can account for data that are not easily accommodated by load theory or generalized slowing. For example, Braver et al. (2001) utilized the AX-CPT task that requires a response to a probe (X) only if it follows a specific cue (A), and to withhold responses otherwise. During the task, older adults displayed higher false alarms (X preceded by the wrong cue) as well as increased correct rejections (withhold response to non-X probes cued by A), suggesting that older adults did not properly utilize the contextual cue information. This model may also help explain age-related declines in utilizing predictive cues to form expectations that may otherwise enhance behavioural performance (see section on temporal attention). Neurally, this

model attributes contextual control to the dorsolateral prefrontal cortex and postulates that declines in context processing stem from impairment of a gating mechanism that is mediated by dopaminergic projections to that brain region. Due to the incorporation of the prefrontal cortex in explaining cognitive decline, the context model is compatible with the frontal lobe hypothesis (West and Schwarz 2006) and extends its basic tenets to a specific neuromodulatory mechanism.

Although neuroimaging research provides support for the frontal lobe hypothesis, additional subtleties have been observed. As mentioned throughout this chapter, older adults appear to utilize additional prefrontal cortical regions to compensate for declines in attentional processes. During various tasks, younger adults often utilize lateral prefrontal cortical regions, whereas older adults recruit an additional contralateral homologue in order to retain performance abilities (Reuter-Lorenz et al. 2000; Rypma and D'Esposito 2000). These findings form the basis of the hemispheric asymmetry reduction in older adults (HAROLD) model and this asymmetry reduction in ageing has been observed in the domains of working memory, episodic memory, perceptual processes, and inhibitory control (Cabeza 2002; Daselaar and Cabeza 2005). Interestingly, some research indicates that asymmetry reduction is further pronounced in more advanced years (75–80 years of age) than in earlier elder years (60–70 years of age). This could indicate that asymmetry reduction may serve as a marker for some forms of neurocognitive decline. However, it should be noted that not all neural recruitment in older adults can be considered compensatory. Within-group analysis has shown that older adults with bilateral activity may perform worse than older adults with more unilateral activity, and that only certain contralateral homologues may be compensatory based on interhemispheric connectivity (Colcombe et al. 2005). Nonetheless, the HAROLD model is largely based on research in the memory domain and additional research will be required to ascertain its significance for attentional processes in ageing aside from inhibitory control.

Although neuroimaging research has indicated that older adults rely on more prefrontal cortical areas during attention-demanding tasks, this does not always reflect an asymmetry reduction as younger adults may utilize posterior occipito-temporal regions in lieu of frontal cortical function (Grady et al. 1994; Madden et al. 2002; Cabeza et al. 2004). This posterior to anterior shift in ageing (PASA) observation is thought to represent compensatory mechanisms in older adults, and not merely a reflection of task difficulty (Davis et al. 2008). Importantly, Davis et al. (2008) also demonstrate the generalizability of PASA to posterior cortical deactivations, suggesting that ageing results in a global shift in brain function that is not exclusive to the prefrontal cortex. However, ageing differences are most prominent under increased attentional demand and PASA does not appear to be contingent on task difficulty. Thus, additional concepts must be incorporated to account for these discrepancies.

The compensation-related utilization of neural circuits hypothesis (or CRUNCH) has attempted to account for age-related changes as a function of task difficulty, as well as incorporate why prefrontal neural recruitment may not always be compensatory (Reuter-Lorenz and Lustig 2005; Reuter-Lorenz and Cappell 2008). This hypothesis

suggests that age-related neural compensation is effective with low task demands, but that age-related declines in performance become apparent with increasing task difficulty as a resource limit is reached. This is effectively similar to load theory in attributing cognitive load limitations to declines observed in ageing. Yet, CRUNCH incorporates differential neural activity profiles in ageing and provides a means to regain or retain functionality in ageing through interventions such as cognitive training or exercise (Reuter-Lorenz and Mikels 2006). These interventions may serve to enhance compensatory potential by increasing available cognitive resources (Stern et al. 2005).

Along similar lines, the scaffolding theory of ageing and cognition (STAC) invokes plasticity as a central mechanism by which detrimental effects of ageing may be minimized (Park and Reuter-Lorenz 2009). Scaffolding refers to the neural dynamics that occur in response to challenge and is a normal and adaptive process that is present throughout the lifespan. The central tenet of STAC is that in response to ageing, older adults may form new scaffolds or recruit previously established scaffolds that formed during early development or new learning. Due to age-related cortical shrinkage, white matter degradation, and dopamine depletion, scaffolding acts particularly in the prefrontal cortex to support cognitive function in response to neural declines. Although scaffolding is thought to be more prevalent in older adults due to increased challenge with lower task demands, scaffolding in older adults is less plastic and may be less efficient than in younger adults. This age-related loss in scaffolding quality and efficiency may result in cognitive performance deficits, especially with increased task difficulty. As such, STAC is compatible with other theories that posit age-related deficiencies stem from limited cognitive resources and predicts that scaffolding cannot compensate for cognitive processes that exceed available resources during high task demands. STAC incorporates many strengths of the previously mentioned theories on cognitive ageing, yet it is a more recent theory and only time will tell whether the scaffolding theory will withstand the pressure of future scientific scrutiny.

Whereas PASA, CRUNCH, and STAC each may incorporate age-based changes within any region of the cortex, the focus is generally on the prefrontal cortex. Although hypotheses based on frontal lobe dysfunction have had great success in explaining many age-related declines in cognition, West (1996) acknowledges that other neural regions may be diminished in ageing that could account for what frontal lobe-based hypotheses cannot. Indeed, attentional processes are distributed among frontal and posterior neural networks (e.g. Corbetta and Shulman 2002) and age-related changes are most likely widespread throughout the brain (Salthouse et al. 1996a). Thus, more generalized neuropsychologically based approaches may be required.

The cognitive reserve hypothesis stems from the repeated observation that the amount of brain pathology or damage does not necessarily relate to the clinical manifestation of the damage (Stern 2002). This hypothesis forms an important distinction between reserves and compensation. Essentially, cognitive reserve refers to the ability to maximize normal performance whereas compensation is the attempt to maximize performance following brain damage by recruiting neural regions that would not otherwise be involved in the task. Importantly, indices of cognitive reserve have been positively

associated with cognitive performance in multiple domains including attention and memory (e.g. Corral et al. 2006). Notably, the cognitive reserve hypothesis is compatible with other theories invoking capacity limits and compensatory measures, yet it retains some generalizability to differentially address age-related changes in cognitive reserves and compensatory mechanisms.

Arguably, the most generalizable neural model for cognitive ageing suggests that neural noise throughout the brain may account for age-related declines in various cognitive tasks (Crossman and Szafran 1956; Welford 1981). As a formalized model, Li and colleagues (Li et al. 2001; Li 2005) propose the dopaminergic system modulates the neural signal to noise ratio, which is decreased (increased noise) in older adults. Although the neural noise, context, and scaffolding models incorporate dopaminergic processes as a source of age-based decline, the neural noise model is not specific to the prefrontal cortex, nor does it invoke the use of context. Yet, similar to other models, it incorporates generalized slowing that is consistently observed throughout the ageing literature. In the neural noise model, a decreased signal to noise ratio may lead to slowing at information processing stages in order to properly evaluate perceptual representations. Single-cell recordings in animals as well as human neuroimaging have supported this hypothesis to show that the aged brain yields broader tuning curves and less precision of attribute- and category-specific coding in posterior cortices (reviewed in Reuter-Lorenz and Lustig 2005). Importantly, variability in measures of visual and auditory function strongly relate to age-based variance on cognitive assessments such as reasoning, fluency, memory, knowledge, and speed (Lindenberger and Baltes 1994; Salthouse et al. 1996b; Baltes and Lindenberger 1997). Of current interest, some research has indicated that certain attentional processes may serve to reduce neural noise in older adults with a disproportional improvement in performance relative to younger adults (Allen et al. 1992; Bucur et al. 2005). Thus, additional research will be required to fully ascertain the role of attention and neural noise in ageing.

From the viewpoint of attention deficits being an underlying factor in the widespread impairment associated with cognitive ageing, emerging evidence based on neural data shows consistent deficits in top-down modulation in older adults (Gazzaley 2012). Top-down modulation, defined as the modulation of neural activity in neurons of sensory or motor areas based on an individual's goals, involves the enhancement of task-relevant representations and/or suppression for task-irrelevant representations. Top-down modulation can occur, both when stimuli are present in the environment, and when stimuli are absent and representations are generated solely based on goals. It thus serves a critical role at the crossroads of perception, attention, and memory abilities (Gazzaley 2011; Gazzaley and Nobre 2012). As discussed throughout this chapter, it is becoming evident that healthy older adults exhibit a top-down modulation deficit both when stimuli are present (e.g. perceptual discrimination, memory encoding) and when stimuli are absent from the environment (e.g. working memory maintenance, memory retrieval, mental imagery, and stimulus expectation, both for object-category and timing). Importantly, these neural deficits are associated with broad performance deficits (e.g. working memory, episodic memory, and perception). Top-down modulation may serve to alter internal signal to noise ratios in a manner posited by neural noise

theories. Furthermore, it should be noted that many examples of age-related declines in top-down modulation are associated specifically with a failure to suppress neural activity to irrelevant information, which has been suggested to act as a neural basis that links theories on inhibition and processing speed (Gazzaley et al. 2008). Consistent with other theories of cognitive ageing, it has been proposed that age-related changes in top-down modulation are mediated by alterations in fronto-posterior neural networks. Thus, age-related deficits in top-down modulation may play a key role in why older adults exhibit widespread cognitive decline.

Overall, there are many theories on the basis of cognitive ageing as it relates to attentional processes. Although no one theory may account for the plethora of age-related changes observed in the literature, many of the most common aspects of attention and ageing have been taken into account. Specifically, current theories have incorporated generalized slowing, reduced inhibitory processes, the retention of performance abilities, as well as declines in performance with increased task difficulty. Current theories on attention and ageing are often successful because they incorporate the strengths of previous theories. Although each theory has had success in attributing some cognitive declines to one deficient mechanism, age-related changes appear to be multidimensional and, as such, theories on cognitive ageing should be as well. Thus, future theories should continue to capitalize on the strengths of current models and attempt to further integrate the vast array of cognitive changes in ageing.

## CONCLUSION

---

The currently available research on attention and ageing is vast and complex with many conflicting reports. However, this literature may be simplified, and some discrepant evidence may be consolidated, by accounting for the heterogeneity of the ageing population, as well as the many various forms of attentional processes. Here, we addressed attention as it pertains to normal ageing. However, it should be noted that what we consider 'normal' ageing might not be very normal in terms of historical human life expectancy, or overall population norms. Nonetheless, older adults without clinically identified pathology display great heterogeneity in performance during attention-demanding tasks, such that some older adults exhibit pronounced decline whereas others perform on a par with younger adults. It is not clear that all aspects of attention are affected by ageing, especially once changes in bottom-up sensory deficits or generalized slowing are taken into account. Namely, older adults often retain the ability to orient attention to a spatial location, ignore intermodal distraction, scan mental images, and perform local task-switching. However, it still remains to be seen whether deficits in these abilities are evident when task demands are increased. What has emerged from the literature is that age-based declines have been reported during many tasks with low cognitive demands on selective attention, divided attention, sustained attention, global task-switching, and controlling attentional capture.

Compensatory mechanisms, particularly in the prefrontal cortex, are thought to help retain certain performance abilities in ageing. However, it is unclear which processes are in need of compensation. A likely candidate is that bottom-up sensory processes decline in ageing due to reduced neural specialization (Park et al. 2004), which may affect multiple cognitive domains (Baltes and Lindenberger 1997). Therefore, additional attentional processes may be recruited via enhanced frontal cortical activity to discriminate between different perceptual representations. Yet as task difficulty increases, age-related declines in attention become more prominent. This suggests that as task difficulty increases, either neural recruitment is insufficient to compensate for declines in bottom-up processes, or older adults have declines in their top-down attentional mechanisms, such as capacity limitations or inefficient context processing. Thus, additional research will be required to fully understand the nature of compensatory recruitment.

Fortunately, the older brain retains plasticity abilities and as such, cognitive training and exercise may help reduce negative effects of age on attention. Interestingly, several studies have indicated how prior occupation may benefit older adults in attentional abilities that are specific to their previous line of work. This implies that personal experiences throughout the lifespan may help dictate how well attentional abilities are retained in later stages of life. Therefore, there is no need to wait for a noticeable decline in attention to begin cognitive training and/or exercising. It seems we are all fighting against the clock and it is time to pay attention.

## REFERENCES

- Adrover-Roig, D. and Barcelo, F. (2010). Individual differences in aging and cognitive control modulate the neural indexes of context updating and maintenance during task-switching. *Cortex* 46: 434–450.
- Agus, T. R., Akeroyd, M. A., Gatehouse, S., and Warden D. (2009). Informational masking in young and elderly listeners for speech masked by simultaneous speech and noise. *Journal of the Acoustical Society of America* 126: 1926–1940.
- Alden, J. D., Harrison, D. W., Snyder, K. A., and Everhart, D. E. (1997). Age differences in intention to left and right hemispace using a dichotic listening paradigm. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology* 10: 239–242.
- Allen, P. A., Madden, D. J., Groth, K. E., and Crozier, L. C. (1992). Impact of age, redundancy, and perceptual noise on visual-search. *Journal of Gerontology* 47: P69–P74.
- Allen, P. A., Smith, A. F., Vires-Collins, H., and Sperry, S. (1998). The psychological refractory period: Evidence for age differences in attentional time-sharing. *Psychology and Aging* 13: 218–229.
- Andersson, M., Reinvang, I., Wehling, E., Hugdahl, K., and Lundervold, A. J. (2008). A dichotic listening study of attention control in older adults. *Scandinavian Journal of Psychology* 49: 299–304.
- Bacon, W. F. and Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics* 55: 485–496.
- Balci, F., Meck, W. H., Moore, H., and Brunner, D. (2009). Timing deficits in aging and neuropathology. In J. L. Bizon and A. Woods (eds.), *Animal Models of Human Cognitive Aging* (pp. 161–201). Totowa, N.J.: Humana Press.

- Baltes, P. B. and Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging* 12: 12–21.
- Barrett, A. M. and Craver-Lemley, C. E. (2008). Is it what you see, or how you say it? Spatial bias in young and aged subjects. *Journal of the International Neuropsychological Society* 14: 562–570.
- Basak, C., Boot, W. R., Voss, M. W., and Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging* 23: 765–777.
- Beaman, C. P. (2005). Irrelevant sound effects amongst younger and older adults: Objective findings and subjective insights. *European Journal of Cognitive Psychology* 17: 241–265.
- Bell, R. and Buchner, A. (2007). Equivalent irrelevant-sound effects for old and young adults. *Memory & Cognition* 35: 352–364.
- Belleville, S., Rouleau, N., Van der Linden, M., and Collette, F. (2003). Effect of manipulation and irrelevant noise on working memory capacity of patients with Alzheimer's dementia. *Neuropsychology* 17: 69–81.
- Bennett, I. J., Golob, E. J., and Starr, A. (2004). Age-related differences in auditory event-related potentials during a cued attention task. *Clinical Neurophysiology* 115: 2602–2615.
- Berardi, A., Parasuraman, R., and Haxby, J. V. (2001). Overall vigilance and sustained attention decrements in healthy aging. *Experimental Aging Research* 27: 19–39.
- Berger, L. and Bernard-Demanze, L. (2011). Age-related effects of a memorizing spatial task in the adults and elderly postural control. *Gait & Posture* 33: 300–302.
- Bherer, L., Desjardins, S., and Fortin, C. (2007). Age-related differences in timing with breaks. *Psychology and Aging* 22: 398–403.
- Bherer, L., Kramer, A. F., and Peterson, M. S. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research* 34: 188–219.
- Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., and Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging* 20: 695–709.
- Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., and Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: Application to attentional control. *Acta Psychologica* 123: 261–278.
- Bialystok, E., Craik, F. I. M., Grady, C., Chau, W., Ishii, R., Gunji, A., and Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: Evidence from MEG. *NeuroImage* 24: 40–49.
- Bialystok, E., Craik, F. I. M., Klein, R., and Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging* 19: 290–303.
- Birren, J. E. and Fisher, L. M. (1995). Aging and speed of behaviour: Possible consequences for psychological functioning. *Annual Review of Psychology* 46: 329–353.
- Block, R. A., Zakay, D., and Hancock, P. A. (1998). Human aging and duration judgments: A meta-analytic review. *Psychology and Aging* 13: 584–596.
- Bojko, A., Kramer, A. F., and Peterson, M. S. (2004). Age equivalence in switch costs for prosaccade and antisaccade tasks. *Psychology and Aging* 19: 226–234.
- Bollinger, J., Rubens, M. T., Masangkay, E., and Gazzaley, A. (2011). An expectation-based memory deficit in aging. *Neuropsychologia* 49: 1466–1475.
- Bollinger, J., Rubens, M. T., Zanto, T. P., and Gazzaley, A. (2010). Expectation-driven changes in cortical functional connectivity influence working-memory and long-term memory performance. *Journal of Neuroscience* 30: 14399–14410.

- Bouma, A. and Gootjes, L. (2011). Effects of attention on dichotic listening in elderly and patients with dementia of the Alzheimer type. *Brain and Cognition* 76: 286–293.
- Braver, T. S. and Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience and Biobehavioral Reviews* 26: 809–817.
- Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., Janowsky, J. S., Taylor, S. F., Yesavage, J. A., Mumenthaler, M. S., Jagust, W. J., and Reed, B. R. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General* 130: 746–763.
- Braver, T. S., Reynolds, J. R., and Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron* 39: 713–726.
- Brodeur, D. A. and Enns, J. T. (1997). Covert visual orienting across the lifespan. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Experimentale* 51: 20–35.
- Bruyer, R. and Scailquin, J. C. (2000). Effects of aging on the generation of mental images. *Experimental Aging Research* 26: 337–351.
- Bucur, B., Madden, D. J., and Allen, P. A. (2005). Age-related differences in the processing of redundant visual dimensions. *Psychology and Aging* 20: 435–446.
- Bunce, D. J., Barrowclough, A., and Morris, I. (1996). The moderating influence of physical fitness on age gradients in vigilance and serial choice responding tasks. *Psychology and Aging* 11: 671–682.
- Bunce D. J., Warr, P. B., and Cochrane, T. (1993). Blocks in choice responding as a function of age and physical-fitness. *Psychology and Aging* 8: 26–33.
- Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging* 17: 85–100.
- Cabeza, R., Daselaar, S. M., Dolcos, F., Prince, S. E., Budde, M., and Nyberg, L. (2004). Task-independent and task-specific age effects on brain activity during working memory, visual attention and episodic retrieval. *Cerebral Cortex* 14: 364–375.
- Campbell, K. L., Al-Aidroos, N., Fatt, R., Pratt, J., and Hasher, L. (2010). The effects of multi-sensory targets on saccadic trajectory deviations: Eliminating age differences. *Experimental Brain Research* 201: 385–392.
- Carhart, R. and Tillman, T. W. (1970). Interaction of competing speech signals with hearing losses. *Archives of Otolaryngology* 91: 273–279.
- Carriere, J. S.A., Cheyne, J. A., Solman, G. J. F., and Smilek, D. (2010). Age trends for failures of sustained attention. *Psychology and Aging* 25: 569–574.
- Castel, A. D., Balota, D. A., Hutchison, K. A., Logan, J. M., and Yap, M. J. (2007). Spatial attention and response control in healthy younger and older adults and individuals with Alzheimer's disease: Evidence for disproportionate selection impairments in the Simon task. *Neuropsychology* 21: 170–182.
- Castel, A. D., Chasteen, A. L., Scialfa, C. T., and Pratt, J. (2003). Adult age differences in the time course of inhibition of return. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 58: P256–P259.
- Cepeda, N. J., Kramer, A. F., and de Sather, J. C. M. G. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology* 37: 715–730.
- Cerella, J. (1985). Age-related decline in extrafoveal letter perception. *Journal of Gerontology* 40: 727–736.

- Chao, L. L. and Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex* 7: 63–69.
- Clapp, W. C. and Gazzaley, A. (2012). Distinct mechanisms for the impact of distraction and interruption on working memory in aging. *Neurobiology of Aging* 33: 134–148.
- Clapp, W. C., Rubens, M. T., Sabharwal, J., and Gazzaley, A. (2011). Deficit in switching between functional brain networks underlies the impact of multitasking on working memory in older adults. *Proceedings of the National Academy of Sciences USA* 108(17): 7212–7217.
- Cohn, N. B., Dustman, R. E., and Bradford, D. C. (1984). Age-related decrements in Stroop color test-performance. *Journal of Clinical Psychology* 40: 1244–1250.
- Colcombe, S. J., Kramer, A. F., Erickson, K. I., and Scaff, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in inhibitory function in aging humans. *Psychology and Aging* 20: 363–375.
- Colcombe, A. M., Kramer, A. F., Irwin, D. E., Peterson, M. S., Colcombe, S., and Hahn, S. (2003). Age-related effects of attentional and oculomotor capture by onsets and color singletons as a function of experience. *Acta Psychologica* 113: 205–225.
- Comalli, P. E., Wapner, S., and Werner, H. (1962). Interference effects of Stroop color-word test on childhood, adulthood, and aging. *Journal of Genetic Psychology* 100: 47–53.
- Connelly, S. L. and Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance* 19: 1238–1250.
- Corbetta, M. and Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience* 3: 201–215.
- Corral, M., Rodriguez, M., Amenedo, E., Sanchez, J. L., and Diaz, F. (2006). Cognitive reserve, age, and neuropsychological performance in healthy participants. *Developmental Neuropsychology* 29: 479–491.
- Costello, M. C., Madden, D. J., Shepler, A. M., Mitroff, S. R., and Leber, A. B. (2010). Age-related preservation of top-down control over distraction in visual search. *Experimental Aging Research* 36: 249–272.
- Coubard, O. A., Ferruffino, L., Boura, M., Gripon, A., Renaud, M., and Bherer, L. (2011). Attentional control in normal aging and Alzheimer's disease. *Neuropsychology* 25: 353–367.
- Coull, J. T. and Nobre, A. C. (1998). Where and when to pay attention: The neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience* 18: 7426–7435.
- Craft, J. L. and Simon, J. R. (1970). Processing symbolic information from a visual display: Interference from an irrelevant directional cue. *Journal of Experimental Psychology* 83: 415.
- Craik, F. I. M. and Dirks, E. (1992). Age-related differences in 3 tests of visual-imagery. *Psychology and Aging* 7: 661–665.
- Crossman, E. R. and Szafran, J. (1956). Changes in age with the speed of information-intake and discrimination. *Experientia Supplementum* 4: 128–134.
- Curran, T., Hills, A., Patterson, M. B., and Strauss, M. E. (2001). Effects of aging on visuospatial attention: An ERP study. *Neuropsychologia* 39: 288–301.
- Damoiseaux, J. S., Beckmann, C. F., Arigita, E. J. S., Barkhof, F., Scheltens, P., Stam, C. J., Smith, S. M., and Rombouts, S. (2008). Reduced resting-state brain activity in the 'default network' in normal aging. *Cerebral Cortex* 18: 1856–1864.
- Daselaar, S. and Cabeza, R. (2005). Age-related changes in hemispheric organization. In R. Cabeza, L. Nyberg, and D. Park (eds.), *Cognitive Neuroscience of Aging: Linking Cognitive and Cerebral Aging* (pp. 325–353). New York: Oxford University Press.

- Davies, D. R. and Parasuraman, R. (1982). *The Psychology of Vigilance*. London: Academic Press.
- Davis, S. W., Dennis, N. A., Daselaar, S. M., Fleck, M. S., and Cabeza, R. (2008). Que PASA? The posterior–anterior shift in aging. *Cerebral Cortex* 18: 1201–1209.
- De Beni, R., Pazzaglia, F., and Gardini, S. (2007). The generation and maintenance of visual mental images: Evidence from image type and aging. *Brain and Cognition* 63: 271–278.
- Deiber, M. P., Rodriguez, C., Jaques, D., Missonnier, P., Emch, J., Millet, P., Gold, G., Giannakopoulos, P., and Ibanez, V. (2010). Aging effects on selective attention-related electroencephalographic patterns during face encoding. *Neuroscience* 171: 173–186.
- Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review* 12: 45–75.
- Diederich, A., Colonius, H., and Schomburg, A. (2008). Assessing age-related multisensory enhancement with the time-window-of-integration model. *Neuropsychologia* 46: 2556–2562.
- DiGirolamo, G. J., Kramer, A. F., Barad, V., Cepeda, N. J., Weissman, D. H., Milham, M. P., Wszalek, T. M., Cohen, N. J., Banich, M. T., Webb, A., Belopolsky, A. V., and McAuley, E. (2001). General and task-specific frontal lobe recruitment in older adults during executive processes: A fMRI investigation of task-switching. *NeuroReport* 12: 2065–2071.
- Dorbath, L., Hasselhorn, M., and Titz, C. (2011). Aging and executive functioning: A training study on focus-switching. *Frontiers in Psychology* 2: 257. doi: 10.3389/fpsyg.2011.00257.
- Dorbath, L. and Titz, C. (2011). Dissociable age effects in focus-switching: Out of sight, out of mind. *GeroPsych* 24: 103–109.
- Drag, L. L. and Bieliauskas, L. A. (2010). Contemporary review 2009: Cognitive aging. *Journal of Geriatric Psychiatry and Neurology* 23: 75–93.
- Dror, I. E. and Kosslyn, S. M. (1994). Mental imagery and aging. *Psychology and Aging* 9: 90–102.
- Duquesnoy, A. J. (1983). Effect of single interfering noise or speech source upon the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America* 74: 739–743.
- Earles, J. L., Connor, L. T., Frieske, D., Park, D. C., Smith, A. D., and Zwahr, M. (1997). Age differences in inhibition: Possible causes and consequences. *Aging, Neuropsychology and Cognition* 4: 45–57.
- Egly, R., Driver, J., and Rafal, R. D. (1994). Shifting visual-attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General* 123: 161–177.
- Einstein, G. O., Earles, J. L., and Collins, H. M. (2002). Gaze aversion: Spared inhibition for visual distraction in older adults. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 57: P65–P73.
- Ergenoglu, T., Demiralp, T., Bayraktaroglu, Z., Ergen, M., Beydagi, H., and Uresin, Y. (2004). Alpha rhythm of the EEG modulates visual detection performance in humans. *Cognitive Brain Research* 20: 376–383.
- Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., Kim, J. S., Alvarado, M., and Kramer, A. F. (2007). Training-induced plasticity in older adults: Effects of training on hemispheric asymmetry. *Neurobiology of Aging* 28: 272–283.
- Eriksen, B. A. and Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a nonsearch task. *Perception & Psychophysics* 16: 143–149.
- Falkenstein, M., Hoormann, J., and Hohnsbein, J. (2001). Changes of error-related ERPs with age. *Experimental Brain Research* 138: 258–262.
- Fernandes, M. A., Pacurar, A., Moscovitch, M., and Grady, C. (2006). Neural correlates of auditory recognition under full and divided attention in younger and older adults. *Neuropsychologia* 44: 2452–2464.

- Fernandez-Duque, D. and Black, S. E. (2006). Attentional networks in normal aging and Alzheimer's disease. *Neuropsychology* 20: 133–143.
- Filley, C. M. and Cullum, C. M. (1994). Attention and vigilance functions in normal aging. *Applied Neuropsychology* 1: 29–32.
- Folk, C. L. and Hoyer, W. J. (1992). Aging and shifts of visual spatial attention. *Psychology and Aging* 7: 453–465.
- Fortin, C. (2003). Attentional time-sharing in interval timing. In W. H. Meck (ed.), *Functional and Neural Mechanisms of Interval Timing* (pp. 235–259). Boca Raton, Fla.: CRC Press.
- Gamboz, N., Russo, R., and Fox, E. (2002). Age differences and the identity negative priming effect: An updated meta-analysis. *Psychology and Aging* 17: 525–531.
- Gazzaley, A. (2011). Influence of early attentional modulation on working memory. *Neuropsychologia* 49: 1410–1423.
- Gazzaley, A. (2012). Top-down modulation deficit in the aging brain: An emerging theory of cognitive aging. In D. T. Stuss and R. T. Knight (eds.), *Principles of Frontal Lobe Function*, 2nd edn. (pp. 593–608). New York: Oxford University Press.
- Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R., and D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings of the National Academy of Sciences USA* 105: 13122–13126.
- Gazzaley, A., Cooney, J. W., Rissman, J., and D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience* 8: 1298–1300.
- Gazzaley, A. and Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences* 16: 129–135.
- Gazzaley, A., Rissman, J., Cooney, J., Rutman, A., Seibert, T., Clapp, W., and D'Esposito, M. (2007). Functional interactions between prefrontal and visual association cortex contribute to top-down modulation of visual processing. *Cerebral Cortex* 17: I125–I135.
- Giambra, L. M. (1993). Sustained attention in older adults: Performance and processes. In J. Cerella, J. Rybash, W. Hoyer, and M. L. Commons (eds.), *Adult Information Processing: Limits on Loss* (pp. 259–272). San Diego: Academic Press.
- Giambra, L. M. (1997). Sustained attention and aging: Overcoming the decrement? *Experimental Aging Research* 23: 145–161.
- Glass, J. M., Schumacher, E. H., Lauber, E. J., Zurbruggen, E. L., Gmeindl, L., Kieras, D. E., and Meyer, D. E. (2000). Aging and the psychological refractory period: Task-coordination strategies in young and old adults. *Psychology and Aging* 15: 571–595.
- Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (ed.), *Brain Aging: Models, Methods, and Mechanisms* (pp. 3–20). Boca Raton, Fla.: CRC Press.
- Goffaux, P., Phillips, N. A., Sinai, M., and Pushkar, D. (2008). Neurophysiological measures of task-set switching: Effects of working memory and aging. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 63: P57–P66.
- Gooch, C. M., Stern, Y., and Rakitin, B. C. (2009). Evidence for age-related changes to temporal attention and memory from the choice time production task. *Neuropsychology, Development, and Cognition B: Aging, Neuropsychology, and Cognition* 16: 285–310.
- Gootjes, L., Scheltens, P., Van Strien, J. W., and Bouma, A. (2007). Subcortical white matter pathology as a mediating factor for age-related decreased performance in dichotic listening. *Neuropsychologia* 45: 2322–2332.
- Gootjes, L., Van Strien, J. W., and Bouma, A. (2004). Age effects in identifying and localising dichotic stimuli: A corpus callosum deficit? *Journal of Clinical and Experimental Neuropsychology* 26: 826–837.

- Gottlob, L. R. and Madden, D. J. (1998). Time course of allocation of visual attention after equating for sensory differences: An age-related perspective. *Psychology and Aging* 13: 138–149.
- Grady, C. L., Maisog, J. M., Horwitz, B., Ungerleider, L. G., Mentis, M. J., Salerno, J. A., Pietrini, P., Wagner, E., and Haxby, J. V. (1994). Age-related changes in cortical blood flow activation during visual processing of faces and location. *Journal of Neuroscience* 14: 1450–1462.
- Grady, C. L., Protzner, A. B., Kovacevic, N., Strother, S. C., Afshin-Pour, B., Wojtowicz, M., Anderson, J. A. E., Churchill, N., and McIntosh, A. R. (2010). A multivariate analysis of age-related differences in default mode and task-positive networks across multiple cognitive domains. *Cerebral Cortex* 20: 1432–1447.
- Guerreiro, M. J. S., Murphy, D. R., and Van Gerven, P. W. M. (2010). The role of sensory modality in age-related distraction: A critical review and a renewed view. *Psychological Bulletin* 136: 975–1022.
- Guerreiro, M. J. and Van Gerven, P. W. (2011). Now you see it, now you don't: Evidence for age-dependent and age-independent cross-modal distraction. *Psychology and Aging* 26: 415–426.
- Gunstad, J., Cohen, R. A., Paul, R. H., Luyster, F. S., and Gordon, E. (2006). Age effects in time estimation: Relationship to frontal brain morphometry. *Journal of Integrative Neuroscience* 5: 75–87.
- Gusnard, D. A., Akbudak, E., Shulman, G. L., and Raichle, M. E. (2001). Medial prefrontal cortex and self-referential mental activity: Relation to a default mode of brain function. *Proceedings of the National Academy of Sciences USA* 98: 4259–4264.
- Hahn, M., Falkenstein, M., and Wild-Wall, N. (2010). Age-related performance differences in compensatory tracking under a dual task condition. *Occupational Ergonomics* 9: 75–8686.
- Hahn, S. and Kramer, A. F. (1995). Attentional flexibility and aging: You don't need to be 20 years of age to split the beam. *Psychology and Aging* 10: 597–609.
- Hallgren, M., Larsby, B., Lyxell, B., and Arlinger, S. (2001). Cognitive effects in dichotic speech testing in elderly persons. *Ear and Hearing* 22: 120–129.
- Hampshire, A., Gruszka, A., Fallon, S. J., and Owen, A. M. (2008). Inefficiency in self-organized attentional switching in the normal aging population is associated with decreased activity in the ventrolateral prefrontal cortex. *Journal of Cognitive Neuroscience* 20: 1670–1686.
- Handy, T. C., Soltani, M., and Mangun, G. R. (2001). Perceptual load and visuocortical processing: Event-related potentials reveal sensory-level selection. *Psychological Science* 12: 213–218.
- Hanslmayr, S., Aslan, A., Staudigl, T., Klimesch, W., Herrmann, C. S., and Bauml, K. H. (2007). Prestimulus oscillations predict between and within subjects. *NeuroImage* 37: 1465–1473.
- Hartley, A. A. (1992). Attention. In F. I. Craik and T. A. Salthouse (eds.), *The Handbook of Aging and Cognition* (pp. 3–50). Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old-age. *Psychology and Aging* 8: 371–379.
- Hartley, A. A., Jonides, J., and Sylvester, C. Y. C. (2011). Dual-task processing in younger and older adults: Similarities and differences revealed by fMRI. *Brain and Cognition* 75: 281–291.
- Hartley, A. A., Kieley, J. M., and Slabach, E. H. (1990). Age differences and similarities in the effects of cues and prompts. *Journal of Experimental Psychology: Human Perception and Performance* 16: 523–537.
- Hartley, A. A. and Little, D. M. (1999). Age-related differences and similarities in dual-task interference. *Journal of Experimental Psychology: General* 128: 416–449.
- Hasbroucq, T. and Guiard, Y. (1992). The effects of intensity and irrelevant location of a tactile stimulation in a choice reaction-time-task. *Neuropsychologia* 30: 91–94.

- Hasher, L., Lustig, C., and Zacks, J. M. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. Kane, A. Miyake, and J. Towse (eds.), *Variation in Working Memory* (pp. 227–249). New York: Oxford University Press.
- Hasher, L., Stoltzfus, E. R., Zacks, R. T., and Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 17: 163–169.
- Hasher, L. and Zacks, R. T. (1988). Working memory, comprehension and aging: A review and a new view. In G. H. Bower (ed.), *The Psychology of Learning and Motivation* (pp. 193–225). New York: Academic Press.
- Hasher, L., Zacks, R. T., and May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher and A. Koriati (eds.), *Attention and Performance: Cognitive Regulation of Performance—Interaction of Theory and Application* (vol. 15, pp. 653–675). Cambridge, Mass.: MIT Press.
- Hawkins, H. L., Kramer, A. F., and Capaldi, D. (1992). Aging, exercise, and attention. *Psychology and Aging* 7: 643–653.
- Helfer, K. S., Chevalier, J., and Freyman, R. L. (2010). Aging, spatial cues, and single- versus dual-task performance in competing speech perception. *Journal of the Acoustical Society of America* 128: 3625–3633.
- Helfer, K. S. and Freyman, R. L. (2008). Aging and speech-on-speech masking. *Ear and Hearing* 29: 87–98.
- Hillyard, S. A. (1969). Relationships between contingent negative variation (CNV) and reaction time. *Physiology & Behavior* 4: 351.
- Hommel, B., Li, K. Z. H., and Li, S. C. (2004). Visual search across the life span. *Developmental Psychology* 40: 545–558.
- Hommet, C., Mondon, K., Berrut, G., Gouyer, Y., Isingrini, M., Constans, T., and Belzung, C. (2010). Central auditory processing in aging: The dichotic listening paradigm. *Journal of Nutrition, Health & Aging* 14: 751–756.
- Hugenschmidt, C. E., Peiffer, A. M., McCoy, T. P., Hayasaka, S., and Laurienti, P. J. (2009). Preservation of crossmodal selective attention in healthy aging. *Experimental Brain Research* 198: 273–285.
- Humes, L. E., Lee, J. H., and Coughlin, M. P. (2006). Auditory measures of selective and divided attention in young and older adults using single-talker competition. *Journal of the Acoustical Society of America* 120: 2926–2937.
- Iarocci, G., Enns, J. T., Randolph, B., and Burack, J. A. (2009). The modulation of visual orienting reflexes across the lifespan. *Developmental Science* 12: 715–724.
- James, W. (1890). *The Principles of Psychology*. New York: Holt.
- Johannsen, P., Jakobsen, J., Bruhn, P., Hansen, S. B., Gee, A., Stodkilde-Jorgensen, H., and Gjedde, A. (1997). Cortical sites of sustained and divided attention in normal elderly humans. *NeuroImage* 6: 145–155.
- Johnson, R. C., Cole, R. E., Bowers, J. K., Foiles, S. V., Nikaido, A. M., Patrick, J. W., and Woliver, R. E. (1979). Hemispheric efficiency in middle and later adulthood. *Cortex* 15: 109–119.
- Juncos-Rabadan, O., Pereiro, A. X., and Facal, D. (2008). Cognitive interference and aging: Insights from a spatial stimulus-response consistency task. *Acta Psychologica* 127: 237–246.
- Juola, J. F., Koshino, H., Warner, C. B., Mckell, M., and Peterson, M. (2000). Automatic and voluntary control of attention in young and older adults. *American Journal of Psychology* 113: 159–178.
- Kalkstein, J., Checksfield, K., Bollinger, J., and Gazzaley, A. (2011). Diminished top-down control underlies a visual imagery deficit in normal aging. *Journal of Neuroscience* 31: 15768–15774.

- Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., and Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 64: 356–363.
- Kawai, N. and Kubo-Kawai, N. (2010). Elimination of the enhanced Simon effect for older adults in a three-choice situation: Ageing and the Simon effect in a go/no-go Simon task. *Quarterly Journal of Experimental Psychology* 63: 452–464.
- Kenemans, J. L., Smulders, F. T. Y., and Kok, A. (1995). Selective processing of 2-dimensional visual-stimuli in young and old subjects: Electrophysiological analysis. *Psychophysiology* 32: 108–120.
- Kerr, B., Condon, S. M., and McDonald, L. A. (1985). Cognitive spatial processing and the regulation of posture. *Journal of Experimental Psychology: Human Perception and Performance* 11: 617–622.
- Keskinen, E., Ota, H., and Katila, A. (1998). Older drivers fail in intersections: Speed discrepancies between older and younger male drivers. *Accident: Analysis and Prevention* 30: 323–330.
- Kim, S., Hasher, L., and Zacks, R. T. (2007). Aging and a benefit of distractibility. *Psychonomic Bulletin & Review* 14: 301–305.
- Kimberg, D. Y., Aguirre, G. K., and D'Esposito, M. (2000). Modulation task-related neural activity in task-switching: An fMRI study. *Cognitive Brain Research* 10: 189–196.
- Klein, M., Ponds, R. W. H. M., Houx, P. J., and Jolles, J. (1997). Effect of test duration on age-related differences in Stroop interference. *Journal of Clinical and Experimental Neuropsychology* 19: 77–82.
- Koch, W., Teipel, S., Mueller, S., Buerger, K., Bokde, A. L. W., Hampel, H., Coates, U., Reiser, M., and Meindl, T. (2010). Effects of aging on default mode network activity in resting state fMRI: Does the method of analysis matter? *NeuroImage* 51: 280–287.
- Kok, A. (2000). Age-related changes in involuntary and voluntary attention as reflected in components of the event-related potential (ERP). *Biological Psychology* 54: 107–143.
- Kosslyn, S. M., Pascual-Leone, A., Felician, O., Camposano, S., Keenan, J. P., Thompson, W. L., Ganis, G., Sukel, K. E., and Alpert, N. M. (1999). The role of area 17 in visual imagery: Convergent evidence from PET and rTMS. *Science* 284: 167–170.
- Kosslyn, S. M., Thompson, W. L., and Alpert, N. M. (1997). Neural systems shared by visual imagery and visual perception: A positron emission tomography study. *NeuroImage* 6: 320–334.
- Kramer, A. F., Hahn, S., and Gopher, D. (1999a). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica* 101: 339–378.
- Kramer, A. F., Hahn, S., Irwin, D. E., and Theeuwes, J. (1999b). Attentional capture and aging: Implications for visual search performance and oculomotor control. *Psychology and Aging* 14: 135–154.
- Kramer, A. F., Hahn, S., Irwin, D. E., and Theeuwes, J. (2000). Age differences in the control of looking behavior: Do you know where your eyes have been? *Psychological Science* 11: 210–217.
- Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., and Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging* 9: 491–512.
- Kramer, A. F. and Larish, J. (1996). Aging and dual-task performance. In W. R. Rogers, A. D. Fisk, and N. Walker (eds.), *Aging and Skilled Performance* (pp. 83–112). Hillsdale, N.J.: Lawrence Erlbaum Associates.

- Kramer A. F. and Madden D. J. (2008). Attention. In F. I. Craik and T. A. Salthouse (eds.), *The Handbook of Aging and Cognition*, 3rd edn. (pp. 189–250). New York: Psychology Press.
- Kray, J. (2006). Task-set switching under cue-based versus memory-based switching conditions in younger and older adults. *Brain Research* 1105: 83–92.
- Kray, J., Li, K. Z. H., and Lindenberger, U. (2002). Age-related changes in task-switching components: The role of task uncertainty. *Brain and Cognition* 49: 363–381.
- Kray, J. and Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging* 15: 126–147.
- Langley, L. K., Friesen, C. K., Saville, A. L., and Ciernia, A. T. (2011). Timing of reflexive visuospatial orienting in young, young-old, and old-old adults. *Attention, Perception, & Psychophysics* 73: 1546–1561.
- Laurienti, P. J., Burdette, J. H., Maldjian, J. A., and Wallace, M. T. (2006). Enhanced multisensory integration in older adults. *Neurobiology of Aging* 27: 1155–1163.
- Lavie, N., Hirst, A., de Fockert, J. W., and Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General* 133: 339–354.
- Lavie, N. and Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual-attention. *Perception & Psychophysics* 56: 183–197.
- Leber, A. B. and Egeth, H. E. (2006). It's under control: Top-down search strategies can override attentional capture. *Psychonomic Bulletin & Review* 13: 132–138.
- Leuthold, H. and Schroter, H. (2006). Electrophysiological evidence for response priming and conflict regulation in the auditory Simon task. *Brain Research* 1097: 167–180.
- Li, L., Daneman, M., Qi, J. G., and Schneider, B. A. (2004). Does the information content of an irrelevant source differentially affect spoken word recognition in younger and older adults? *Journal of Experimental Psychology: Human Perception and Performance* 30: 1077–1091.
- Li, S. C. (2005). Neurocomputational perspectives linking neuromodulation, processing noise, representational distinctiveness, and cognitive aging. In R. Cabeza, L. Nyberg, and D. Park (eds.), *Cognitive Neuroscience of Aging: Linking Cognitive and Cerebral Aging* (pp. 354–379). New York: Oxford University Press.
- Li, S. C., Lindenberger, U., and Sikstrom, S. (2001). Aging cognition: From neuromodulation to representation. *Trends in Cognitive Sciences* 5: 479–486.
- Lincourt, A. E., Folk, C. L., and Hoyer, W. J. (1997). Effects of aging on voluntary and involuntary shifts of attention. *Aging, Neuropsychology, and Cognition* 4: 290–303.
- Lindenberger, U. and Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging* 9: 339–355.
- Lindenberger, U., Kliegl, R., and Baltes, P. B. (1992). Professional expertise does not eliminate age differences in imagery-based memory performance during adulthood. *Psychology and Aging* 7: 585–593.
- Lorenzo-Lopez, L., Amenedo, E., and Cadaveira, F. (2008a). Feature processing during visual search in normal aging: Electrophysiological evidence. *Neurobiology of Aging* 29: 1101–1110.
- Lorenzo-Lopez, L., Amenedo, E., Pascual-Marqui, R. D., and Cadaveira, F. (2008b). Neural correlates of age-related visual search decline: A combined ERP and sLORETA study. *NeuroImage* 41: 511–524.
- Lorenzo-Lopez, L., Doallo, S., Vizoso, C., Amenedo, E., Holguin, S. R., and Cadaveira, F. (2002). Covert orienting of visuospatial attention in the early stages of aging. *NeuroReport* 13: 1459–1462.

- Lustig, C. (2003). Grandfather's clock: Attention and interval timing in older adults. In W. H. Meck (ed.), *Functional and Neural Mechanisms of Interval Timing* (pp. 261–293). Boca Raton, Fla.: CRC Press.
- Lustig, C., Snyder, A. Z., Bhakta, M., O'Brien, K. C., McAvoy, M., Raichle, M. E., Morris, J. C., and Buckner, R. L. (2003). Functional deactivations: Change with age and dementia of the Alzheimer type. *Proceedings of the National Academy of Sciences USA* 100: 14504–14509.
- McDowd, J.M. and Craik, F. I. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance* 14: 267–280.
- McDowd, J. M. and Shaw, R. J. (2000). Attention and aging: A functional perspective. In F. I. Craik and T. A. Salthouse (eds.), *Handbook of Aging and Cognition*, 2nd edn. (pp. 221–292). Hillsdale, N.J.: Lawrence Erlbaum Associates.
- McLaughlin, P. M., Szostak, C., Binns, M. A., Craik, F. I. M., Tipper, S. P., and Stuss, D. T. (2010). The effects of age and task demands on visual selective attention. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Experimentale* 64: 197–207.
- Madden, D. J. (2007). Aging and visual attention. *Current Directions in Psychological Science* 16: 70–74.
- Madden, D. J., Blumenthal, J. A., Allen, P. A., and Emery, C. F. (1989). Improving aerobic capacity in healthy older adults does not necessarily lead to improved cognitive performance. *Psychology and Aging* 4: 307–320.
- Madden, D. J., Costello, M. C., Dennis, N. A., Davis, S. W., Shepler, A. M., Spaniol, J., Bucur, B., and Cabeza, R. (2010). Adult age differences in functional connectivity during executive control. *NeuroImage* 52: 643–657.
- Madden, D. J. and Gottlob, L. R. (1997). Adult age differences in strategic and dynamic components of focusing visual attention. *Aging, Neuropsychology, and Cognition* 4: 185–210.
- Madden, D. J. and Langley, L. K. (2003). Age-related changes in selective attention and perceptual load during visual search. *Psychology and Aging* 18: 54–67.
- Madden, D. J., Spaniol, J., Bucur, B., and Whiting, W. L. (2007a). Age-related increase in top-down activation of visual features. *Quarterly Journal of Experimental Psychology* 60: 644–651.
- Madden, D. J., Spaniol, J., Whiting, W. L., Bucur, B., Provenzale, J. M., Cabeza, R., White, L. E., and Huettel, S. A. (2007b). Adult age differences in the functional neuroanatomy of visual attention: A combined fMRI and DTI study. *Neurobiology of Aging* 28: 459–476.
- Madden, D. J., Turkington, T. G., Provenzale, J. M., Denny, L. L., Langley, L. K., Hawk, T. C., and Coleman, R. E. (2002). Aging and attentional guidance during visual search: Functional neuroanatomy by positron emission tomography. *Psychology and Aging* 17: 24–43.
- Madden, D. J. and Whiting, W. L. (2004). Age-related changes in visual attention. In P. T. Costa and I. C. Siegler (eds.), *Recent Advances in Psychology and Aging* (pp. 41–88). Amsterdam: Elsevier.
- Madden, D. J., Whiting, W. L., Cabeza, R., and Huettel, S. A. (2004). Age-related preservation of top-down attentional guidance during visual search. *Psychology and Aging* 19: 304–309.
- Madden, D. J., Whiting, W. L., Spaniol, J., and Bucur, B. (2005). Adult age differences in the implicit and explicit components of top-down attentional guidance during visual search. *Psychology and Aging* 20: 317–329.
- Malouin, F., Richards, C. L., Jackson, P. L., Dumas, F., and Doyon, J. (2003). Brain activations during motor imagery of locomotor-related tasks: A PET study. *Human Brain Mapping* 19: 47–62.

- Mani, T. M., Bedwell, J. S., and Miller, L. S. (2005). Age-related decrements in performance on a brief continuous performance test. *Archives of Clinical Neuropsychology* 20: 575–586.
- Mapstone, M., Dickerson, K., and Duffy, C. J. (2008). Distinct mechanisms of impairment in cognitive ageing and Alzheimer's disease. *Brain* 131: 1618–1629.
- Martin, J. S. and Jerger, J. F. (2005). Some effects of aging on central auditory processing. *Journal of Rehabilitation Research and Development* 42: 25–44.
- Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., and Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science* 315: 393–395.
- Mathewson, K. J., Dywan, J., and Segalowitz, S. J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology* 70: 88–104.
- Maylor, E. A. and Lavie, N. (1998). The influence of perceptual load on age differences in selective attention. *Psychology and Aging* 13: 563–573.
- Mayr, U. and Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 26: 1124–1140.
- Mayr, U. and Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology* 13: 47–69.
- Mechelli, A., Price, C. J., Friston, K. J., and Ishai, A. (2004). Where bottom-up meets top-down: Neuronal interactions during perception and imagery. *Cerebral Cortex* 14: 1256–1265.
- Meijer, W. A., de Groot, R. H. M., Van Boxtel, M. P. J., Van Gerven, P. W. M., and Jolles, J. (2006). Verbal learning and aging: Combined effects of irrelevant speech, interstimulus interval, and education. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 61: P285–P294.
- Miniussi, C., Wilding, E. L., Coull, J. T., and Nobre, A. C. (1999). Orienting attention in time: Modulation of brain potentials. *Brain* 122: 1507–1518.
- Mouloua, M. and Parasuraman, R. (1995). Aging and cognitive vigilance: Effects of spatial uncertainty and event rate. *Experimental Aging Research* 21: 17–32.
- Munsell, O. S. (1873). *Psychology; or, The Science of Mind*. New York: D. Appleton.
- Nagamatsu, L. S., Carolan, P., Liu-Ambrose, T. Y. L., and Handy, T. C. (2011). Age-related changes in the attentional control of visual cortex: A selective problem in the left visual hemifield. *Neuropsychologia* 49: 1670–1678.
- Nagamatsu, L. S., Liu-Ambrose, T. Y. L., Carolan, P., and Handy, T. C. (2009). Are impairments in visual-spatial attention a critical factor for increased falls risk in seniors? An event-related potential study. *Neuropsychologia* 47: 2749–2755.
- Neider, M. B., Gaspar, J. G., McCarley, J. S., Crowell, J. A., Kaczmarek, H., and Kramer, A. F. (2011). Walking and talking: Dual-task effects on street crossing behavior in older adults. *Psychology and Aging* 26: 260–268.
- Nissen, M. J. and Corkin, S. (1985). Effectiveness of attentional cueing in older and younger adults. *Journal of Gerontology* 40: 185–191.
- Nobre, A. C., Correa, A., and Coull, J. T. (2007). The hazards of time. *Current Opinion in Neurobiology* 17: 465–470.
- Nobre, A. C., Rao, A. L., and Chelazzi, L. (2006). Selective attention to specific features within objects: Behavioral and electrophysiological evidence. *Journal of Cognitive Neuroscience* 18: 539–561.
- Northoff, G., Heinzel, A., Greck, M., Bennpohl, F., Dobrowolny, H., and Panksepp, J. (2006). Self-referential processing in our brain: A meta-analysis of imaging studies on the self. *NeuroImage* 31: 440–457.

- O'Craven, K. M. and Kanwisher, N. (2000). Mental imagery of faces and places activates corresponding stimulus-specific brain regions. *Journal of Cognitive Neuroscience* 12: 1013–1023.
- Olk, B., Cameron, B., and Kingstone, A. (2008). Enhanced orienting effects: Evidence for an interaction principle. *Visual Cognition* 16: 979–1000.
- Parasuraman, R. (1998). The attentive brain: Issues and prospects. In R. Parasuraman (ed.), *The Attentive Brain* (pp. 3–15). Cambridge, Mass.: MIT Press.
- Parasuraman, R. and Giambra, L. (1991). Skill development in vigilance: Effects of event rate and age. *Psychology and Aging* 6: 155–169.
- Parasuraman, R., Nestor, P., and Greenwood, P. (1989). Sustained-attention capacity in young and older adults. *Psychology and Aging* 4: 339–345.
- Park, D. C., Polk, T. A., Park, R., Minear, M., Savage, A., and Smith, M. R. (2004). Aging reduces neural specialization in ventral visual cortex. *Proceedings of the National Academy of Sciences USA* 101: 13091–13095.
- Park, D. C. and Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology* 60: 173–196.
- Peiffer, A. M., Hugenschmidt, C. E., Maldjian, J. A., Casanova, R., Srikanth, R., Hayasaka, S., Burdette, J. H., Kraft, R. A., and Laurienti, P. J. (2009). Aging and the interaction of sensory cortical function and structure. *Human Brain Mapping* 30: 228–240.
- Peiffer, A. M., Mozolic, J. L., Hugenschmidt, C. E., and Laurienti, P. J. (2007). Age-related multisensory enhancement in a simple audiovisual detection task. *NeuroReport* 18: 1077–1081.
- Persson, J., Lustig, C., Nelson, J. K., and Reuter-Lorenz, P. A. (2007). Age differences in deactivation: A link to cognitive control? *Journal of Cognitive Neuroscience* 19: 1021–1032.
- Pick, D. F. and Proctor, R. W. (1999). Age differences in the effects of irrelevant location information. In M. Scerbo and M. W. Mouloua (eds.), *Automation Technology and Human Performance* (pp. 258–261). Mahwah, N.J.: Lawrence Erlbaum Associates.
- Plude, D. J. and Doussard-Roosevelt, J. A. (1989). Aging, selective attention, and feature integration. *Psychology and Aging* 4: 98–105.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology* 32: 3–25.
- Praamstra, P., Kourtis, D., Kwok, H. F., and Oostenveld, R. (2006). Neurophysiology of implicit timing in serial choice reaction-time performance. *Journal of Neuroscience* 26: 5448–5455.
- Pratt, J. and Bellomo, C. N. (1999). Attentional capture in younger and older adults. *Aging, Neuropsychology, and Cognition* 6: 19–31.
- Proctor, R. W., Pick, D. F., Vu, K. P. L., and Anderson, R. E. (2005). The enhanced Simon effect for older adults is reduced when the irrelevant location information is conveyed by an accessory stimulus. *Acta Psychologica* 119: 21–40.
- Quigley, C., Andersen, S. K., Schulze, L., Grunwald, M., and Muller, M. M. (2010). Feature-selective attention: Evidence for a decline in old age. *Neuroscience Letters* 474: 5–8.
- Rabbitt, P., Lunn, M., Pendleton, N., Horan, M., Scott, M., Thacker, N., Lowe, C., and Jackson, A. (2007a). White matter lesions account for all age-related declines in speed but not in intelligence. *Neuropsychology* 21: 363–370.
- Rabbitt, P., Mogapi, O., Scott, M., Thacker, N., Lowe, C., Horan, M., Pendleton, N., Jackson, A., and Lunn, D. (2007b). Effects of global atrophy, white matter lesions, and cerebral blood flow on age-related changes in speed, memory, intelligence, vocabulary, and frontal function. *Neuropsychology* 21: 684–695.

- Raz, N., Briggs, S. D., Marks, W., and Acker J. D. (1999). Age-related deficits in generation and manipulation of mental images. II: The role of dorsolateral prefrontal cortex. *Psychology and Aging* 14: 436–444.
- Rees, G., Frith, C. D., and Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science* 278: 1616–1619.
- Reuter-Lorenz, P. A. and Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science* 17: 177–182.
- Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., and Koeppel, R. A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience* 12: 174–187.
- Reuter-Lorenz, P. A. and Lustig, C. (2005). Brain aging: Reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology* 15: 245–251.
- Reuter-Lorenz, P. A. and Mikels, J. A. (2006). The aging mind and brain: Implication of enduring plasticity for behavioral and cultural change. In P. Baltes, P.A. Reuter-Lorenz, and F. Roesler (eds.), *Lifespan Development and the Brain: The Perspective of Biocultural Co-constructivism* (pp. 255–276). Cambridge: Cambridge University Press.
- Ristic, J. and Kingstone, A. (2006). Attention to arrows: Pointing to a new direction. *Quarterly Journal of Experimental Psychology* 59: 1921–1930.
- Rodriguez, V., Valdes-Sosa, M., and Freiwald, W. (2002). Dividing attention between form and motion during transparent surface perception. *Cognitive Brain Research* 13: 187–193.
- Rogers, R. D., Sahakian, B. J., Hodges, J. R., Polkey, C. E., Kennard, C., and Robbins, T. W. (1998). Dissociating executive mechanisms of task control following frontal lobe damage and Parkinson's disease. *Brain* 121: 815–842.
- Rogers, W. (2000). Attention and aging. In D. Park and N. Schwarz (eds.), *Cognitive Aging: A Primer* (pp. 57–73). New York: Psychology Press.
- Rorden, C., Guerrini, C., Swainson, R., Lazzari, M., and Baylis, G. C. (2008). Event related potentials reveal that increasing perceptual load leads to increased responses for target stimuli and decreased responses for irrelevant stimuli. *Frontiers in Human Neuroscience* 2: 4. doi: 10.3389/neuro.09.004.2008.
- Rosselli, M. and Salvatierra, J. L. (2011). The effect of bilingualism and age on inhibitory control. *International Journal of Bilingualism* 15: 26–37.
- Rossi-Katz, J. and Arehart, K. H. (2009). Message and talker identification in older adults: Effects of task, distinctiveness of the talkers' voices, and meaningfulness of the competing message. *Journal of Speech, Language, and Hearing Research* 52: 435–453.
- Rouleau, N. and Belleville, S. (1996). Irrelevant speech effect in aging: An assessment of inhibitory processes in working memory. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 51: P356–P363.
- Rushworth, M. F. S., Hadland, K. A., Paus, T., and Sipila, P. K. (2002). Role of the human medial frontal cortex in task switching: A combined fMRI and TMS study. *Journal of Neurophysiology* 87: 2577–2592.
- Rypma, B. and D'Esposito, M. (2000). Isolating the neural mechanisms of age-related changes in human working memory. *Nature Neuroscience* 3: 509–515.
- Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren and K. W. Schaie (eds.), *Handbook of the Psychology of Aging* (pp. 400–426). New York: Van Nostrand Reinhold.
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review* 103: 403–428.

- Salthouse, T. A. (2000). Aging and measures of processing speed. *Biological Psychology* 54: 35–54.
- Salthouse, T. A., Fristoe, B. N., and Rhee, S. H. (1996a). How localized are age-related effects on neuropsychological measures? *Neuropsychology* 10: 272–285.
- Salthouse, T. A., Hancock, H. E., Meinz, E. J., and Hambrick, D. Z. (1996b). Interrelations of age, visual acuity, and cognitive functioning. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 51: P317–330.
- Salthouse, T. A. and Madden, D. J. (2007). Information processing speed and aging. In J. Deluca and J. Kalmar (eds.), *Information Processing Speed in Clinical Populations* (pp. 221–241). New York: Psychology Press.
- Salthouse, T. A. and Meinz, E. J. (1995). Aging, inhibition, working-memory, and speed. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 50: P297–P306.
- Salthouse, T. A., Rogan, J. D., and Prill, K. A. (1984). Division of attention: Age differences on a visually presented memory task. *Memory & Cognition* 12: 613–620.
- Salthouse, T. A., Toth, J., Daniels, K., Parks, C., Pak, R., Wolbrette, M., and Hocking, K. J. (2000). Effects of aging on efficiency of task switching in a variant of the trail making test. *Neuropsychology* 14: 102–111.
- Samanez-Larkin, G. R., Robertson, E. R., Mikels, J. A., Carstensen, L. L., and Gotlib, I. H. (2009). Selective attention to emotion in the aging brain. *Psychology and Aging* 24: 519–529.
- Sambataro, F., Murty, V. P., Callicott, J. H., Tan, H. Y., Das, S., Weinberger, D. R., and Mattay, V. S. (2010). Age-related alterations in default mode network: Impact on working memory performance. *Neurobiology of Aging* 31: 839–852.
- Sarter, M. and Bruno, J. P. (2004). Developmental origins of the age-related decline in cortical cholinergic function and associated cognitive abilities. *Neurobiology of Aging* 25: 1127–1139.
- Schmitz, T. W., Cheng, F. H. T., and De Rosa, E. (2010). Failing to ignore: Paradoxical neural effects of perceptual load on early attentional selection in normal aging. *Journal of Neuroscience* 30: 14750–14758.
- Schneider, B. A. and Pichora-Fuller, M. K. (2000). Implication of perceptual deterioration for cognitive aging research. In F. I. Craik and T. A. Salthouse (eds.), *The Handbook of Aging and Cognition*, 2nd edn. (pp. 155–219). Mahwah, N.J.: Lawrence Erlbaum Associates.
- Schooler, C., Neumann, E., Caplan, L. J., and Roberts, B. R. (1997). Continued inhibitory capacity throughout adulthood: Conceptual negative priming in younger and older adults. *Psychology and Aging* 12: 667–674.
- Sekuler, R., McLaughlin, C., and Yotsumoto, Y. (2008). Age-related changes in attentional tracking of multiple moving objects. *Perception* 37: 867–876.
- Sheridan, P. L. and Hausdorff, J. M. (2007). The role of higher-level cognitive function in gait: Executive dysfunction contributes to fall risk in Alzheimer's disease. *Dementia and Geriatric Cognitive Disorders* 24: 125–137.
- Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology* 81: 174–176.
- Simon, J. R., Craft, J. L., and Webster, J. B. (1971). Reaction time to onset and offset of lights and tones: Reactions toward changed element in a 2-element display. *Journal of Experimental Psychology* 89: 197–202.
- Simon, J. R. and Pouraghabagher, A. R. (1978). The effect of aging on the status of processing in a choice reaction time task. *Journal of Gerontology* 33: 553–561.
- Simone, P. M. and McCormick, E. B. (1999). Effect of a defining feature on negative priming across the life span. *Visual Cognition* 6: 587–606.

- Singh, G., Pichora-Fuller, M. K., and Schneider, B. A. (2008). The effect of age on auditory spatial attention in conditions of real and simulated spatial separation. *Journal of the Acoustical Society of America* 124: 1294–1305.
- Smith, E. E., Geva, A., Jonides, J., Miller, A., Reuter-Lorenz, P., and Koeppel, R. A. (2001). The neural basis of task-switching in working memory: Effects of performance and aging. *Proceedings of the National Academy of Sciences USA* 98: 2095–2100.
- Solbakk, A. K., Alpert, G. F., Furst, A. J., Hale, L. A., Oga, T., Chetty, S., Pickard, N., and Knight, R. T. (2008). Altered prefrontal function with aging: Insights into age-associated performance decline. *Brain Research* 1232: 30–47.
- Somberg, B. L. and Salthouse, T. A. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology: Human Perception and Performance* 8: 651–663.
- Sommers, M. S. (1996). The structural organization of the mental lexicon and its contribution to age-related declines in spoken-word recognition. *Psychology and Aging* 11: 333–341.
- Sommers, M. S. and Danielson, S. M. (1999). Inhibitory processes and spoken word recognition in young and older adults: The interaction of lexical competition and semantic context. *Psychology and Aging* 14: 458–472.
- Sommers, M. S. and Huff, L. M. (2003). The effects of age and dementia of the Alzheimer's type on phonological false memories. *Psychology and Aging* 18: 791–806.
- Spieler, D. H., Balota, D. A., and Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance* 22: 461–479.
- Stegemoller, E. L., Simuni, T., and MacKinnon, C. D. (2009). The effects of Parkinson's disease and age on synopated finger movements. *Brain Research* 1290: 12–20.
- Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society* 8: 448–460.
- Stern, Y., Habeck, C., Moeller, J., Scarmeas, N., Anderson, K. E., Hilton, H. J., Flynn, J., Sackeim, H., and van Heertum, R. (2005). Brain networks associated with cognitive reserve in healthy young and old adults. *Cerebral Cortex* 15: 394–402.
- Stormer, V. S., Li, S. C., Heekeren, H. R., and Lindenberger, U. (2011). Feature-based interference from unattended visual field during attentional tracking in younger and older adults. *Journal of Vision* 11(2): 1.1–12
- Strong, R. (1988). Regionally selective manifestations of neostriatal aging. *Annals of the New York Academy of Sciences* 515: 161–177.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology* 18: 643–662.
- Sullivan, M. P., Faust, M. E., and Balota, D. (1995). Identity negative priming in older adults and individuals with dementia of the Alzheimer-type. *Neuropsychology* 9: 537–555.
- Tales, A., Muir, J. L., Bayer, A., and Snowden, R. J. (2002). Spatial shifts in visual attention in normal ageing and dementia of the Alzheimer type. *Neuropsychologia* 40: 2000–2012.
- Talsma, D., Kok, A., and Ridderinkhof, K. R. (2006). Selective attention to spatial and non-spatial visual stimuli is affected differentially by age: Effects on event-related brain potentials and performance data. *International Journal of Psychophysiology* 62: 249–261.
- Theeuwes, J., Kramer, A. F., Hahn, S., and Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science* 9: 379–385.
- Tipper, S. P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. *Bulletin of the Psychonomic Society* 29: 45–47.
- Townsend, J., Adamo, M., and Haist, F. (2006). Changing channels: An fMRI study of aging and cross-modal attention shifts. *NeuroImage* 31: 1682–1692.

- Trick, L. M., Perl, T., and Sethi, N. (2005). Age-related differences in multiple-object tracking. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 60: P102–P105.
- Tsang, P. S. and Shaner, T. L. (1998). Age, attention, expertise, and time-sharing performance. *Psychology and Aging* 13: 323–347.
- Tun, P. A., O’Kane, G., and Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging* 17: 453–467.
- Tun, P. A. and Wingfield, A. (1999). One voice too many: Adult age differences in language processing with different types of distracting sounds. *Journals of Gerontology B: Psychological Sciences and Social Sciences* 54: P317–P327.
- Turken, A. U., Whitfield-Gabrieli, S., Bammer, R., Baldo, J. V., Dronkers, N. F., Gabrieli, J. D. E. (2008). Cognitive processing speed and the structure of white matter pathways: Convergent evidence from normal variation and lesion studies. *NeuroImage* 42: 1032–1044.
- Ulbrich, P., Churan, J., Fink, M., and Wittmann, M. (2009). Perception of temporal order: The effects of age, sex, and cognitive factors. *Aging, Neuropsychology, and Cognition* 16: 183–202.
- Vallesi, A., McIntosh, A. R., and Stuss, D. T. (2009). Temporal preparation in aging: A functional MRI study. *Neuropsychologia* 47: 2876–2881.
- Van der Lubbe, R. H. J. and Verleger, R. (2002). Aging and the Simon task. *Psychophysiology* 39: 100–110.
- Van Gerven, P. W. M., Meijer, W. A., Vermeeren, A., Vuurman, E. F., and Jolles, J. (2007). The irrelevant speech effect and the level of interference in aging. *Experimental Aging Research* 33: 323–339.
- Van Rooij, J. C. G. M. and Plomp, R. (1991). Auditive and cognitive factors in speech-perception by elderly listeners. *Acta Oto-Laryngologica* 111: 177–181.
- Vecchi, T. and Cornoldi, C. (1999). Passive storage and active manipulation in visuo-spatial working memory: Further evidence from the study of age differences. *European Journal of Cognitive Psychology* 11: 391–406.
- Verhaeghen, P. and Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience & Biobehavioral Reviews* 26: 849–857.
- Verhaeghen, P. and De Meersman, L. (1998). Aging and the negative priming effect: A meta-analysis. *Psychology and Aging* 13: 435–444.
- Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., and Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging* 18: 443–460.
- Vu, K. P. L. and Proctor, R. W. (2008). Age differences in response selection for pure and mixed stimulus-response mappings and tasks. *Acta Psychologica* 129: 49–60.
- Wascher, E., Falkenstein, M., and Wild-Wall, N. (2011). Age related strategic differences in processing irrelevant information. *Neuroscience Letters* 487: 66–69.
- Wasylyshyn, C., Verhaeghen, P., and Sliwinski, M. J. (2011). Aging and task switching: A meta-analysis. *Psychology and Aging* 26: 15–20.
- Wecker, N. S., Kramer, J. H., Wisniewski, A., Delis, D. C., and Kaplan, E. (2000). Age effects on executive ability. *Neuropsychology* 14: 409–414.
- Welford, A. T. (1981). Signal, noise, performance, and age. *Human Factors* 23: 97–109.
- Wenk, G. L., Pierce, D. J., Struble, R. G., Price, D. L., and Cork, L. C. (1989). Age-related changes in multiple neurotransmitter systems in the monkey brain. *Neurobiology of Aging* 10: 11–19.
- West, R. and Bowry, R. (2005). The aging of cognitive control. In R. W. Engle, G. Sedek, U. von Hecker, and D. N. McIntosh (eds.), *Cognitive Limitations in Aging and Psychopathology* (pp. 97–121). Cambridge: Cambridge University Press.

- West, R. and Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology* 20: 468–481.
- West, R. and Travers, S. (2008). Differential effects of aging on processes underlying task switching. *Brain and Cognition* 68: 67–80.
- West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin* 120: 272–292.
- Whiting, W. L., Madden, D. J., and Babcock, K. J. (2007). Overriding age differences in attentional capture with top-down processing. *Psychology and Aging* 22: 223–232.
- Whiting, W. L., Madden, D. J., Pierce, T. W., and Allen, P. A. (2005). Searching from the top down: Ageing and attentional guidance during singleton detection. *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology* 58: 72–97.
- Wild-Wall, N. and Falkenstein, M. (2010). Age-dependent impairment of auditory processing under spatially focused and divided attention: An electrophysiological study. *Biological Psychology* 83: 27–36.
- Wild-Wall, N., Hahn, M., and Falkenstein, M. (2011). Preparatory processes and compensatory effort in older and younger participants in a driving-like dual task. *Human Factors* 53: 91–102.
- Wild-Wall, N., Willemssen, R., and Falkenstein, M. (2009). Feedback-related processes during a time-production task in young and older adults. *Clinical Neurophysiology* 120: 407–413.
- Wilson, R. H. and Jaffe, M. S. (1996). Interactions of age, ear, and stimulus complexity on dichotic digit recognition. *Journal of the American Academy of Audiology* 7: 358–364.
- Woodrow, H. (1914). The measurement of attention. *Psychological Monographs* 17: 1–158.
- Woollacott, M. and Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture* 16: 1–14.
- Wright, L. L. and Elias, J. W. (1979). Age-differences in the effects of perceptual noise. *Journal of Gerontology* 34: 704–708.
- Yamaguchi, S., Tsuchiya, H., and Kobayashi, S. (1995). Electrophysiologic correlates of age effects on visuospatial attention shift. *Cognitive Brain Research* 3: 41–49.
- Yogev-Seligmann, G., Hausdorff, J. M., and Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders* 23: 329–342.
- Zanto, T. P., Hennigan, K., Ostberg, M., Clapp, W. C., and Gazzaley, A. (2010a). Predictive knowledge of stimulus relevance does not influence top-down suppression of irrelevant information in older adults. *Cortex* 46: 561–574.
- Zanto, T. P., Toy, B., and Gazzaley, A. (2010b). Delays in neural processing during working memory encoding in normal aging. *Neuropsychologia* 48: 13–25.
- Zanto, T. P., Pan, P., Liu, H., Bollinger, J., Nobre, A. C., and Gazzaley, A. (2011). Age-related changes in orienting attention in time. *Journal of Neuroscience* 31: 12461–12470.
- Zeef, E. J. and Kok, A. (1993). Age-related differences in the timing of stimulus and response processes during visual selective attention: Performance and psychophysiological analyses. *Psychophysiology* 30: 138–151.
- Zeef, E. J., Sonke, C. J., Kok, A., Buiten, M. M., and Kenemans, J. L. (1996). Perceptual factors affecting age-related differences in focused attention: Performance and psychophysiological analyses. *Psychophysiology* 33: 555–565.