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Review article

Orienting of visual attention in aging

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ABSTRACT

Changes in attention are among the most important cognitive shifts associated with aging, with implications for maintenance of vocational competencies, participation in social interactions, and successful execution of activities of daily living. An important facet of attention is orienting, the ability to selectively attend a location or modality and thereby engender perceptual augmentation. Orienting also involves shifting of the focus of attention in response to unanticipated salient events. Aging may impact orienting through a variety of neurocognitive mechanisms and the interactions between them. We review findings regarding factors that mediate the impact of aging on orienting, including overt vs. covert attending, exogenous vs. endogenous processes, orienting benefits vs. reorienting costs, cue-target onset asynchrony (SOA), post-orienting task factors, and stage of aging. We also consider aging-related changes in the brain substrates of orienting, including cortical and white matter integrity, laterality, connectivity, neuromodulatory functions, and compensatory activity. Taken together, these findings suggest that healthy aging impacts performance on orienting tasks less through direct effects than via interactions with additional cognitive processes.

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1. Understanding the orienting of attention in aging in its cognitive context

Progression through the human lifespan into old age is characterized by a sequence of changes in cognitive processes (Craik and Salthouse, 2011; Greenwood, 2007; Gunning-Dixon and Raz, 2000; Park and Schwarz 2012; Salthouse, 2016; Verhaeghen and Cerella, 2002). Among the cognitive abilities that are essential to our mental function, and subject to such changes, are those that comprise the realm of attention. Although William James famously wrote that everyone knows what attention is (James, 1890), contemporary research continues to provide evidence that attention is not a unitary phenomenon (Fan et al., 2005, 2007; Petersen and Posner, 2012; Posner and Boies, 1971). Rather, it seems best understood as a family of cognitive processes, embodied in dissociable neural networks (Petersen and Posner, 2012). This multi-component approach to attention is supported by a plethora of cognitive, behavioral, neuroimaging, and neuropsychological findings (Fan et al., 2009; Fox et al., 2006; Posner and Fan, 2008; Raz and Buhle, 2006). Accordingly, a properly nuanced understanding of how aging affects attention requires the separate examination of each component of our repertoire of attentional functions.

In this article, we will focus on the aspect of attention that has been called ‘orienting’ (Posner and Petersen, 1990), and survey research that examines how it is affected by aging. Although there are several recent surveys of attention in aging in general (e.g., Drag and Bieliauskas, 2010; Kramer and Madden, 2008; Staub et al., 2013; Verhaeghen and Cerella, 2002; Zanto and Gazzaley, 2014), none of those studies provides a comprehensive view of the orienting aspect of attention, which, as we will argue, is a complex domain in which recent findings and theory call for a re-examination of prior literature. Furthermore, insight into the psychology and neuroscience of orienting is vital for understanding cognitive aging on both theoretical and practical levels.

The notion of orienting our attention is intuitively linked with many activities of daily living. Driving a car, riding a bicycle, or even crossing the street in traffic require rapid spatial awareness of objects in a constantly changing environment. We use our prior knowledge about roads and sidewalks to anticipate oncoming hazards (which can go awry if you are an American crossing a British street), but we can adjust our informational representations and actions if vehicles or pedestrians appear in an unexpected location. Relatedly, quickly finding a friend or a family member in a crowded mall is dependent on our ability to search our environment and to be sensitive to cues indicating the location of the person we seek. Efficiently identifying relevant information on a complicated web page may involve disengaging our concentration from a central item in favor of peripheral icons or text. Decreased ability to perceptually benefit from spatial anticipation, or decline in the ability to change our cognitive commitments in response to the unexpected appearance of salient items, may be quite detrimental to our ability to function in a fast-paced world. Accordingly, exploring if and how such processes may be affected by aging is important for understanding challenges older adults may have in everyday activities. Indeed, it has been suggested that impairments in visual spatial attention may be a critical factor for increased risk of falls in seniors (Ambrose et al., 2013; Nagamatsu et al., 2009, 2013), as well as driving risks of crashes and injuries (Cantin et al., 2009; Myers et al., 2000; Okonkwo et al., 2008; Richardson and Marottoli, 2003; Sims et al., 2000). As we will document below, prior studies offer a complex and often conflicting picture of the status of these attentional functions in aging. We will offer a multifactorial account of those findings that will hopefully ascertain some of the specific conditions under which orienting is affected by aging, as well identify as lines of future research required in order to provide a more integrated understanding of how orienting changes over the later lifespan.

1.1. Attentional networks

In order to understand which cognitive abilities and processes fall under the rubric of orienting, and how they differ from other aspects of attention, we begin with a brief taxonomy of attentional processes based on recent empirical studies and theoretical proposals. While attentional processes may be described and categorized in various ways (e.g., Gazzaley and Nobre, 2012; Verhaeghen and Cerella, 2002), in this review we adopt the approach of Posner and colleagues (Fan et al., 2009; Petersen and Posner, 2012; Posner and Fan, 2008) that conceives of attentional processes in terms of three systems or networks, each serving unique cognitive functions, and identified with specific brain regions and neuromodulatory systems. The following short account of these networks provides a jumping-off point for understanding the context in which attentional orienting takes place.

The first putative attentional system/network is the one responsible for alerting. Alerting is defined as achieving and maintaining a state of optimal vigilance for detecting relevant stimuli and for task performance in general (Fan et al., 2003; Oken et al., 2006; Posner and Boies, 1971). The process of alerting can be defined as preparation for perceiving a stimulus, and is expressed in changes in heart rate and brain oscillatory activity that are responsible for inhibiting competing activities (Kahneman, 1973; Oken et al., 2006). The alerting system is associated with cortical distribution of norepinephrine (NE), and involves thalamic, frontal, and parietal brain regions (Coull et al., 1996; Marrocco et al., 1994; Raz and Buhle, 2006). A common paradigm for testing alerting involves the provision of a temporal warning signal (cue) prior to a target, independent of the target itself. Such cues initiate a change in alertness, by replacing the current resting state with a state of preparation for detection (Posner and Petersen, 1990).

The second network which Posner and colleagues propose as playing a part in attentional function is that of executive control. This system is responsible for information selection in complex tasks, resolution of conflict between competing cognitive processes and responses, and the aspects of coordination involved in process switching (Botvinick et al., 2001; Bush et al., 2000; Monsell, 1996). Executive control of attention has been related to activation of midline frontal areas (anterior cingulate cortex) and the lateral prefrontal cortex (Anderson et al., 2011; Bush et al., 2000; Stuss, 2011; Stuss and Knight, 2013), which are target areas of the ventral tegmental dopamine system (Floresco, 2013; Ko et al., 2013; Puig and Miller, 2014). In everyday life, executive control is most needed in situations that involve problem solving, planning or decision-making, error detection, novel or minimally-learned responses, and overcoming habitual actions. In the laboratory, executive control may be expressed in the withholding of a dominant response in order to execute a task-relevant subdominant response (Botvinick et al., 2001). Accordingly, executive control is relevant to attention task paradigms that require responding to attended target stimuli while inhibiting inappropriate responses evoked by non-target stimuli, as in the Stroop or flanker paradigms (Fan et al., 2005, 2009).

The third type of attention system in Posner's taxonomy, which is the focus of this review, is attentional orienting, responsible for selecting a spatial location or a modality to be the focus of one's perception (Petersen and Posner, 2012). Such orienting will enhance the processing of stimuli or events at that location or in that modality (Eriksen and Hoffman, 1972; Griffin et al., 2002; Posner, 1988), and enable a lower threshold for target detection or discrimination (Bashinski and Bacharach, 1980; Reynolds et al., 2000). Such benefits may be reflected in electrophysiological measures of brain activity (Mangun and Hillyard, 1987; Reynolds et al., 2000). Orienting can be automatic, such as when an exogenous event draws attention to its location, or volitional, as in the endogenous advance selection of a spatial location in which a target is expected. It can be accompanied by head and/or eye movements (overt orienting), or performed without a change in posture or eye position (covert orienting). Orienting typically involves three processes: disengaging from the current focus, shifting to the new location or modality, and engaging attention at the new location or modality (Posner et al., 1984). Importantly, as we will discuss below, orienting is intimately related to awareness of changes in the sensory environment, and responses to them. Spatial attention deficits, such as those characterizing hemispatial neglect, may be seen as types of dysfunctional orienting (Karnath et al., 2004; Mort et al., 2003).

Orienting has been associated with two brain networks (Corbetta and Shulman, 2002; Fig. 1). One is the dorsal fronto-parietal network, including the intraparietal sulcus, the superior parietal lobe, and the superior frontal cortex along the precentral sulcus at the frontal eye fields (Corbetta et al., 2008; Desimone and Duncan, 1995; Vossel et al., 2014). As noted above, orienting facilitates the processing of sensory stimuli based on spatial expectations. Accordingly, the dorsal network is involved in the expectation of seeing an object at a particular location or with certain features (Corbetta et al., 2000, 2002; Hopfinger et al., 2000; Kastner et al., 1999; Shulman et al., 1999). A second, ventral, fronto-parietal network includes the temporo-parietal junction (the posterior sector of the superior temporal sulcus and gyrus and the ventral part of the supramarginal gyrus), as well as the ventral frontal cortex (parts of middle frontal gyrus, inferior frontal gyrus, frontal operculum, and anterior insula). The ventral network is activated when salient unattended objects (or targets) are detected (Arrington et al., 2000; Corbetta et al., 2000, 2008; Kincade et al., 2005; Macaluso et al., 2002; Vossel et al., 2006). Hence, this network is considered responsible for the disengagement of attention from its current location in favor of important relevant stimuli that appear in an unattended location (Corbetta and Shulman, 2002; Corbetta et al., 2008). Studies testing hemispatial neglect following right hemisphere lesions including the abovementioned areas suggests a right lateralization of the brain substrates of this aspect of attention (Bartolomeo et al., 2012; Karnath, 2015; Shulman et al., 2010).

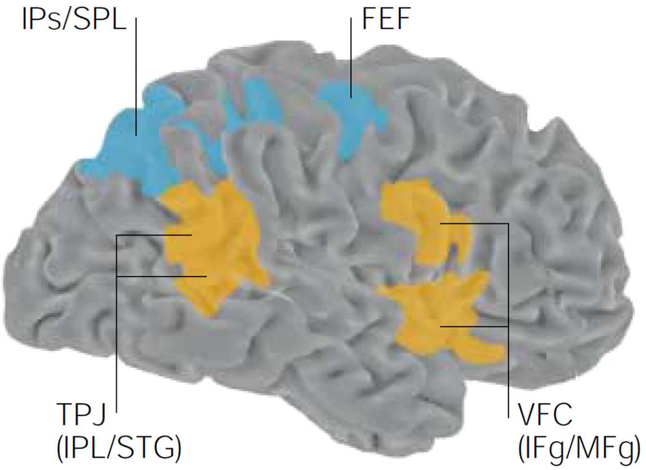

Fig. 1. Dorsal and ventral frontoparietal attention networks as delineated by Corbetta, Shulman, and colleagues. Areas in blue indicate the dorsal frontoparietal network: FEF, frontal eye field; IPs/SPL, intraparietal sulcus/superior parietal lobule. Areas in orange indicate the stimulus-driven ventral frontoparietal network: TPJ, temporoparietal junction (IPL/STG, inferior parietal lobule/superior temporal gyrus); VFC, ventral frontal cortex (IFg/MFg, inferior frontal gyrus/middle frontal gyrus). Reproduced, with permission, from Corbetta and Shulman, 2002. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Orienting attention involves the interaction of processes in the dorsal and ventral networks (Corbetta and Shulman, 2002). While shifting attention activates the dorsal network, reorienting to a new stimulus activates both ventral and dorsal networks. In this conceptualization, the ventral network serves as a ‘circuit breaker’ of the current focus, leading to dorsal processes which shifts attention toward the new object or location of interest. Notably, when reorienting is not required, the ventral network is inhibited to prevent interference (Corbetta et al., 2008). Engagement of the ventral and dorsal orienting networks is seemingly regulated by neuromodulation, and has been associated with cholinergic inputs to the superior parietal lobe (Davidson and Marrocco, 2000; Demeter and Sarter, 2013; Voytko et al., 1994). As we will note below, this identification of interactive but distinguishable brain substrates for the elements of orienting raises the possibility that physiological changes such as those that occur during aging might not identically affect all aspects of orienting.

While there are behavioral studies indicating independence in efficiency and effectiveness of the three system of alerting, executive control, and orienting (Fan et al., 2002, 2009; Fernandez-Duque and Posner, 1997; Gamboz et al., 2010), they subserve attentional functions through coordinated activity. This is indicated by interactions found in measures of performance when several types of attention are required for a given task (e.g., Callejas et al., 2004; Fan et al., 2009). This interaction means that it is important to consider whether aging effects in orienting tasks represent essential changes in the efficiency of orienting proper, or are caused by interactions with those other aspects of attention. In the following survey, we will carefully take such possible interactions into account.

1.2. Aging and the attentional networks

As stated earlier, aging involves various changes in cognitive functioning. Some cognitive functions decline with age, some improve, and others are unaffected (Ben-David et al., 2015; Park and Schwarz, 2012; Raz, 2000). Studies examining age-related aspects of attention indicate different influences of aging on the various functions, supporting claims of independence between relevant networks (e.g., Gamboz et al., 2010; Jennings et al., 2007). Investigation of age-related influences on attention has typically been based on one of two approaches. The first approach focuses on testing a single network at a time, using independent paradigms for testing alertness (Gola et al., 2012), orienting (Bos and Machado, 2013), or executive control (Turner and Spreng, 2012). The second approach is based on using the attention network test (ANT) paradigm, which enables simultaneous testing of each network as well as the interactions between them (Fan et al., 2002, 2005, 2009; Posner and Rothbart, 2007; Raz and Buhle, 2006). Since ANT serves a basis for many studies which we discuss below, we provide a brief description. ANT combines the Posner spatial cueing task (Posner, 1980) and the Eriksen flanker task (Eriksen and Eriksen, 1974). The Posner spatial cueing task employs cues indicating the probable location of an upcoming target (e.g., right/left or top/bottom of a display). In the flanker task, the target stimulus belongs to one of two response categories. The stimulus is presented in the center of a display flanked by additional stimuli (typically two on each side) that belong to either the same or the opposite response category. In the ANT, a cue indicates the location and/or the temporal onset of the upcoming target. When the target is presented, it is flanked by stimuli associated with the same (congruent) or different (incongruent) response category. There are four types of cues (none, double, valid, invalid) that can precede each target stimulus. Double cues (signaling both possible spatial locations) are temporal cues, offering no spatial information. Valid and invalid cues provide both temporal and spatial (location on the screen) information. The valid cue correctly indicates the following target location; the invalid cue indicates the direction opposite to that of the actual target location. Commonly, the target itself is an arrow pointing either to the right or to the left, and the participant's task is to press a key indicating its direction. The flanker arrows can point in the same direction as the target arrow (congruent), or in the opposite direction (incongruent) (Fig. 2). Alertness is assessed by the RT difference between the no-cue condition and the double-cue condition. Orienting is assessed by the RT difference between the invalid and valid cue conditions. Executive control is assessed by the RT difference between the congruent and incongruent trials, averaged across all cueing conditions (Fan et al., 2002, 2005, 2009).

The ANT and other test paradigms can be used to assess aging effects on attention. Interestingly, aging influences on the attentional networks are not clear-cut (Rogers, 2000), with more consistent effects found for alerting, but less consistent impact reported on executive control and orienting. Though the focus of this review is the orienting network, we first present a short summary of age-related influences on alerting and executive control, since those processes may interact with orienting in shaping the attentional abilities of older adults.

1.2.1. Aging influences on alerting

Age-related decline in alerting is a somewhat consistent finding, both in studies testing alerting alone (Gola et al., 2012) and in studies testing alerting together with orienting and executive attention using the ANT paradigm (Gamboz et al., 2010). Though earlier studies suggested that this aspect of attention is generally preserved (Rabbitt, 1984) or even improved (Fernandez-Duque and Black, 2006) in older adults, there is cumulative data indicating reduced alerting abilities in aging (e.g. Festa-Martino et al., 2004; Gamboz et al., 2010; Jennings et al., 2007; Zhou et al., 2011). Recent cueing paradigms which control for confounds such as general slowing (Salthouse, 1996), cue repetitiveness, cue duration, and the lack of temporal uncertainty within blocks indicate age-related decline in alerting, as expressed in the ability to use warning signals to speed responding (Festa-Martino et al., 2004). The diminished alerting effect has been attributed to a decline in attentional resources in aging (Craik and Byrd, 1982; Mahoney et al., 2010; Tun et al., 2009), possibly due to a decline in cortical levels of norepinephrine (Ferrari and Magri, 2008; Lohr and Jeste, 1988; Robertson, 2013).

1.2.2. Aging influences on executive control

Many studies have indicated age-related decline in executive control processes, such as task switching, dual tasking and inhibition (e.g., Cepeda et al., 2001; Hasher et al., 1991; Hasher and Zacks, 1988; Kramer and Kray, 2006; Lawo et al., 2012; Mayr and Liebscher 2001; Meiran and Gotler, 2001; Reimers and Maylor, 2005; Turner and Spreng, 2012; Verhaeghen and Cerella, 2002; Wasylyshyn et al., 2011 Reimers and Maylor, 2005; Turner and Spreng, 2012; Verhaeghen and Cerella, 2002; Wasylyshyn et al., 2011). Of most relevance to executive attention are findings indicating that older adults exhibit declines in inhibiting irrelevant information (Borella et al., 2008; Gazzaley et al., 2005; Hasher and Zacks, 1988; Zanto et al., 2010). These findings are typically explained by the *frontal hypothesis of aging*, according to which many age-related cognitive deficits are associated with deterioration of frontal lobe functions (e.g., Cabeza and Dennis, 2012; Craik, 2006; Crawford et al., 2000; Ferrer-Caja et al., 2002; Troyer et al., 1994). However, studies often fail to demonstrate general age-related executive decline (Fernandez-Duque and Black, 2006; Gamboz et al., 2010; Jennings et al., 2007; Kawai et al., 2012; Kramer et al., 1994; Verhaeghen, 2011; Zanto and Gazzaley, 2014). Hence, the frontal hypothesis of aging has been challenged by several alternatives, including a general slowing account (Salthouse, 1996), examination of dependence on the specific task performed and the specific control process being challenged (Turner and Spreng, 2012), and consideration of the effects of sensory degradation (Ben-David and Schneider, 2009, 2010; Lindenberger and Baltes, 1994; Schneider and Pichora-Fuller, 2000), which may also affect orienting integrity (McCalley et al., 1995).

1.2.3. Aging influences on orienting

The attentional system in which the effects of aging seem to be most heterogeneous is orienting. Various studies of the orienting of attention in old age using diverse paradigms have reported contradictory results (e.g., Folk and Hoyer, 1992; Maylor et al., 2011; Poliakoff et al., 2007). Hence, the balance of this review will focus on orienting, and explore the types of conditions leading to these inconsistent findings. By analyzing the processes involved in the different orienting paradigms, we hope to shed some light on the relationship between aging and orienting (see Fig. 3).

2. Mechanisms of orienting and aging effects

The first challenge in understanding the relationship between orienting and aging relates to the definition of attentional orienting itself. As we explain below, the common definition of orienting as shifting attention toward a sensory signal, or selecting information from sensory input (Petersen and Posner, 2012), has been interpreted in numerous manners, and applied to different aspects of

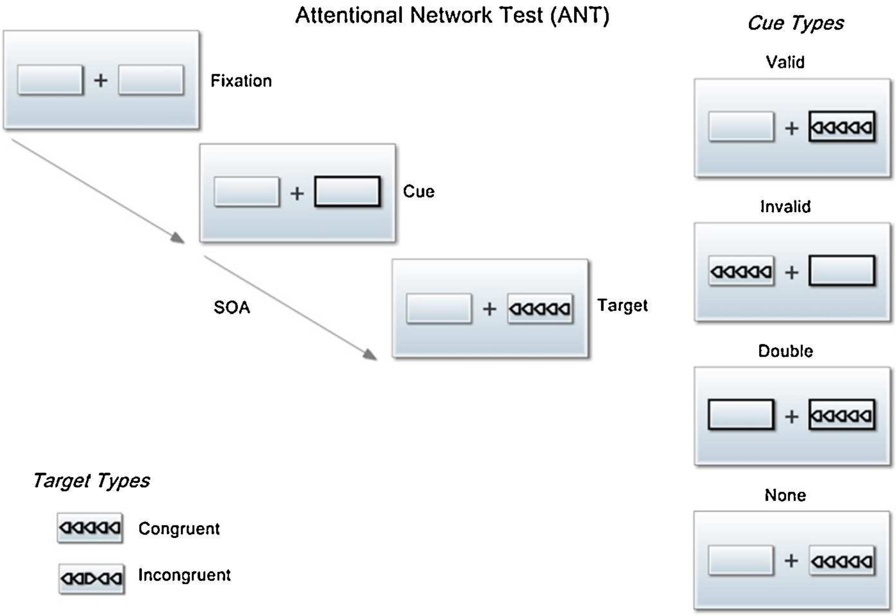

Fig. 2. Attention network test (ANT) paradigm, designed for testing the attentional networks as well as the interactions between them (Fan et al., 2002, 2005, 2009). After fixation, a cue (valid, invalid, double or none) is presented, providing either temporal or spatial and temporal information regarding the target. After a time interval (SOA), the target is presented accompanied by distractors that can be either congruent or incongruent.

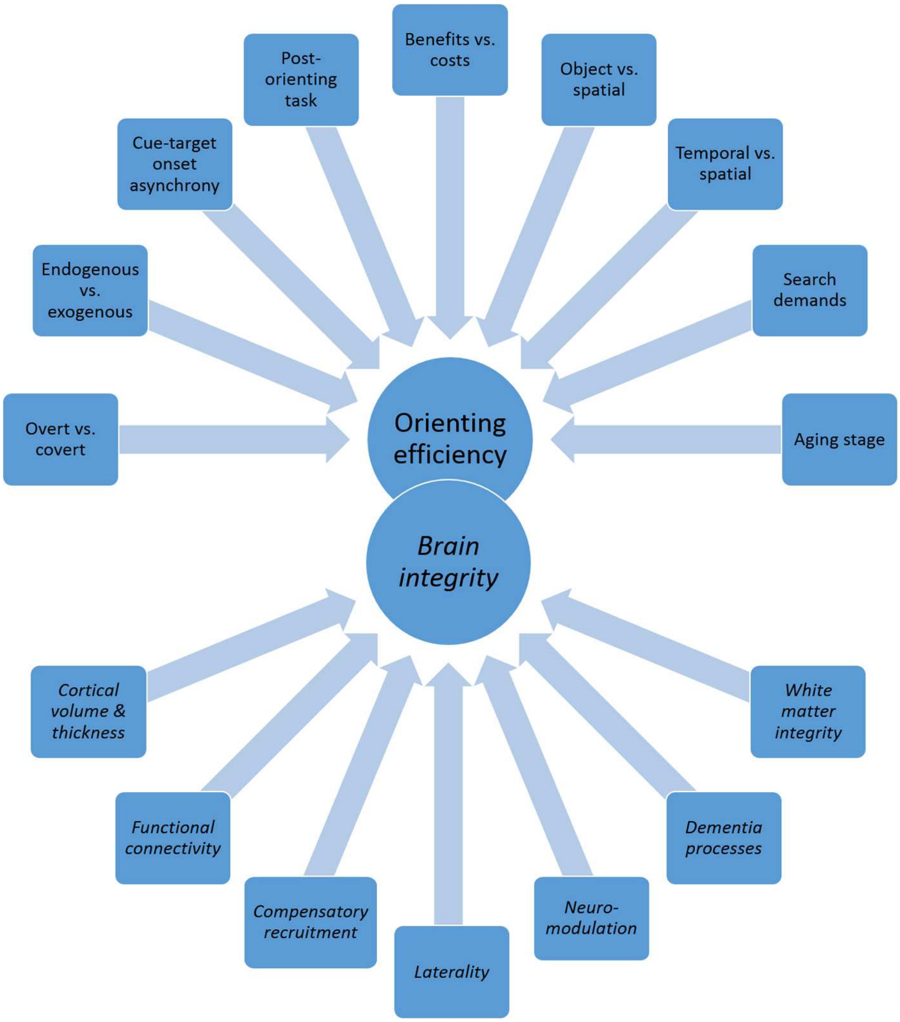

Fig. 3. Overview of the factors suggested to be related to aging influences on the orienting of attention, and of some aging-related changes in the brain substrates of orienting.

visual attention (Chica et al., 2014; Kingstone et al., 2002). Hence, testing attentional orienting can involve several factors potentially affected by aging, including overt vs. covert attending, exogenous vs. endogenous processes, orienting benefits vs. reorienting costs, cue-target delay expressed as stimulus onset asynchrony (SOA), task factors, and aging stage. Additionally, there are complex higher-order forms of orienting such as object-based orienting, visual search, and temporal orienting that call for an even more integrative approach. We will now expand on each of these factors.

3. Core orienting processes

3.1. Overt vs. covert attention

Visual orienting is defined as being either overt or covert (e.g., Posner, 1980; Rafal et al., 1989). Overt orienting involves head and eye movements ending in stimulus foveation, which improves acuity and processing. It is also possible to orient attention covertly without any movement of eye or head position (Posner, 1988). Processing may benefit from just directing the focus of attention to a location where the stimulus is anticipated (Beauchamp et al., 2001). This notion is supported by increase in response efficiency when participants are directed to move their eyes to a target, even before the movement is made. The increased efficiency is attributed to processes taking place before the head and eye moved towards the target (Remington, 1980). Hence, covert attention shifting is considered a preparatory process directing the eye to an appropriate area of the visual field (Fischer and Breitmeyer, 1987; Posner and Cohen, 1984; but see Hunt and Kingstone, 2003). Moreover, it has been suggested that every overt eye movement is preceded by a covert shift of attention (Hoffman and Subramaniam, 1995; Posner, 1980; Remington, 1980), implying a partial overlap between these two types of attention orienting (Beauchamp et al., 2001; Corbetta et al., 1998; Nobre et al., 2000; Rizzolatti et al., 1987; Thompson et al., 2005). This notion is supported by indications that overt and covert shifts of spatial attention are at least partially subserved by similar neural mechanisms, albeit with less activity during covert shifts than during overt shifts. This pattern of activation consists of activity in frontal cortex (especially the precentral sulcus), parietal cortex (especially the intraparietal sulcus), and lateral occipital cortex (Beauchamp et al., 2001). We note that while such neural overlap is found consistently, its interpretation as indicating shared mechanism for overt and covert attention is debated (Klein and Lawrence, 2011). As orienting research is typically interested in the attention aspect of visual perception and not in its eye movement aspects, most studies employ covert shifting tasks, relying on the shared mechanism view.

Importantly, covert and overt forms of shifting attention have been found to differ in aging. While performance on covert shifts of attention may be preserved in aging under a range of conditions as we will document below, older adults' performance is significantly inferior to younger adults when performing overt shifts of attention (Kingstone et al., 2002). If both types of shifting indeed involve the same attentional mechanism (Beauchamp et al., 2001), the interaction can be attributed to changes in non-attentional factors, such as eye and head movement involved in the overt but not in the covert attention shifting. This notion is supported by findings indicating that aging is associated with a decline in eye-movement parameters, such as increased saccadic latencies (Dowiasch et al., 2015; Klein et al., 2000; Warren et al., 2013) and decreased saccadic accuracy (Dowiasch et al., 2015; Ross et al., 1999; Warren et al., 2013). Hence, aging influences on orienting should especially be tested (and commonly are) by employing the covert shifting paradigm, in which participants are required to fixate a central location while stimuli are presented in the periphery. This approach partials out the decline in eye and head movement abilities, enabling a more direct measure of aging effects on attention proper. Furthermore, researchers should monitor eye movements in such covert orienting studies to ensure that age groups do not differ in eye movement errors.

3.2. Endogenous vs. exogenous orienting

Orienting attention is assumed to be governed by one of two modes: endogenous processes, also known as top-down or symbol-interpretation-based orienting (Woldorff et al., 2004), and exogenous processes, also known as bottom-up or involuntary orienting. Endogenous attention orienting is based on one's goals, intentions, or instructions, and typically involves interpretation of a symbol indicating selection criteria for the upcoming stimulus (commonly, its location or onset). Thus, we may be more likely to detect a pedestrian stepping into the road in our direction of travel as opposed to the opposite lane, even if the distance from our car is the same. Attention can also be oriented exogenously, as when captured by salient stimuli (such as luminance changes, onsets, or movement), even if the observer has no advance intention to orient his/her attention to that object or location, and has no benefit from doing so (Jonides, 1981). Thus, a popup message on the margin of our computer screen will distract us from reading what we are looking at. The two orienting modes are sometimes considered as representing competition between inner goals and external demands (Berger et al., 2005) and have even been suggested to trigger different forms of processing (Briand, 1998; Klein, 1994; Funes et al., 2007; but see Müller and Rabbitt, 1989).

In the laboratory, these two types of orienting processes are commonly tested or compared using cue-target paradigms that may differ not only in cue location, but also in cue type, cue validity, and cue-target latency. For example, a central, predictive, spatially symbolic cue that is presented 200 ms or more before the target may be used to elicit endogenous orienting. Such central symbolic cues indicate the spatial location or temporal onset of an upcoming target consistently, or do so with high probability (e.g., 75–80% are "valid" trials). Behaviorally, targets preceded by a valid cue are detected more rapidly and accurately than targets preceded by invalid cues (since subjects interpret the symbolic cue and shift attention towards the cued location endogenously). In these paradigms, cue predictability is important, as non-predictive cues are typically ignored (but see below regarding gaze and arrow cues). The exogenous version of this paradigm consists of peripheral sudden-onset cues (e.g., a box flashed in the left or right parts of the display) that are presented shortly before the target, which appear either at the predicted location (valid) or the opposite location (invalid). Unlike the endogenous version, in this case predictability is not a factor (i.e., there is a 1:1 ratio of valid and invalid trials), and the subject has no reason to use the cue voluntarily. Nonetheless, the detection of the target is faster and more accurate at the location indicated by the cue compared with the opposite location. Notably, this effect depends on the interval between cue and target, and fades or reverses (i.e., Inhibition of Return [IOR]; see below) when the interval is long (Klein, 2000). The two orienting modes, therefore, employ different paradigms which isolate the automatic effects of exogenous capture from the more strategic effects of endogenous control. Orienting cues can also be presented counter-predictively, that is, to predict with high probability that the target will appear at the location contralateral to the cue. In this case, a combination of exogenous and endogenous processes directs attention to opposite locations in space (Chica et al., 2006, 2008; Posner et al., 1982).

Interestingly, the notion that fundamental difference between these two forms of orienting is whether the cue appears at the location of the target is challenged by studies indicating that exogenous orienting can be engendered by central non-predictive symbolic cues such as arrow cues and gaze cues (Friesen and Kingstone, 1998; Gayzur et al., 2014; Ristic et al., 2002; Tipples, 2002). Such cues were found to produce reflexive rather than volitional orienting of attention, even when they are uninformative (Driver et al., 1999; Friesen and Kingstone, 1998; Friesen et al., 2004; Kingstone et al., 2003; Langton and Bruce, 1999; Ristic et al., 2002, 2007; Tipples, 2002). Their effects have been observed at short cue-target intervals (100–300 ms) that do not allow interpretative processing, implying that it is not their predictive properties that direct attention (Galfano et al., 2012; Gayzur et al., 2014; Hommel et al., 2001; Ristic et al., 2007). When long cue-target duration intervals are employed, their cueing effects are no longer observed. Interestingly, such cues do not elicit facilitation for responses to targets at the opposite location of the cue (IOR), as typically observed at long cue-target duration intervals when employing peripheral non-predictive cues (Friesen and Kingstone, 1998). Central symbolic non-predictive cues are thought to represent a special case of cues that have acquired the ability to direct attention automatically due to our experience with them (Kingstone et al., 2003; Ristic and Kingstone, 2006). However, ERP studies comparing this type of cues with purely symbolic cues (e.g., texture) suggest that these behavioral findings are more likely related to an overlearned association rather than to an exogenous attentional process (Brignani et al., 2009). This possibility is supported by indications that gaze-cue orienting is disrupted by working memory load (Bobak and Langton, 2015) and a dissociation between cueing effects on valid vs. invalid trials (Green et al., 2013).

A common question regarding the exogenous and endogenous control modes of attentional orienting is whether they involve different cognitive processes. Jonides (1981) suggested that exogenous orienting, manipulated by peripheral cues capturing attention, is automatic, while endogenous orienting, initiated by interpretation of central symbolic cues, is controlled. Exogenous orienting has been shown to develop more rapidly and yield larger cueing effects (Jonides, 1980; Klein et al., 1992). It is not affected by a secondary memory task or by relative cue frequency (Müller and Rabbitt, 1989). Attention is supposedly captured by the cue and orienting cannot be prevented; once activated, it proceeds in an autonomous fashion (Berger et al., 2005; Müller and Humphreys, 1991; for discussion see Santangelo and Spence, 2008). As for gaze and arrows cues, as they yield rapid orienting as do peripheral cues, and direct attention even when they are not predictive, they are thought to activate reflexive or automatic orienting processes (Ristic and Kingstone, 2006). In contrast, the endogenous mode is affected by competing processes (such as additional cognitive tasks and interference from exogenous orienting mechanisms). The decoding process necessary for the interpretation of central symbolic cues requires resources, and reduces the intensity of the impact of this type of cues (Jonides, 1980; Müller and Rabbitt, 1989). While the difference between the control modes is widely supported (for review, see Chica et al., 2013), some researchers have suggested that the relationship is hierarchical, beginning with exogenous orienting and sometimes (but not always) followed by endogenous control (Awh et al., 2012; Theeuwes, 2010; but see Ansorge et al., 2011). This may be the case in studies employing predictive arrow cues. Likely, these cues represent a combination of automatic and volitional attention orienting (Ristic and Kingstone, 2006).

Behavioral findings suggest that endogenous and exogenous attentional modes involve separate functional substrates, but with some overlap allowing their interaction (Chica et al., 2013; Grubb et al., 2013; Reuter-Lorenz and Fendrich, 1992; Rohenkohl et al., 2011; Rosen et al., 1999 Rosen et al., 1999). Some neuroimaging studies support this notion, indicating that the two modes of orienting are implemented in partially overlapping brain regions (Mysore and Knudsen, 2013; Peelen et al., 2004), while other studies indicate that they recruit different brain systems (Brosch et al., 2011) or at the least that some brain regions (such as the right temporo-parietal junction), are activated in the exogenous but not endogenous orienting of attention (Chica et al., 2011; Kincade et al., 2005) or the other way around (Friedrich et al., 1998; Mayer et al., 2004). Summarizing that literature, Chica et al. (2013) conclude that endogenous and exogenous attention orienting modes are implemented in partially overlapping neural substrates (see also Macaluso and Doricchi, 2013).

Given the aforementioned distinctions in cognitive effects and their brain bases, it is possible that endogenous and exogenous modes of orienting control are influenced differently by aging (see studies listed in Table 1). Generally, it has been reported that older adults shift their attention less rapidly or less effectively in response to central symbolic predictive cues that direct attention to the probable location of target stimuli (endogenous orienting), yet show no deficit in shifting attention in response to peripheral cues capturing attention (exogenous orienting) (Brodeur and Enns, 1997; Craik and Byrd, 1982; Folk and Hoyer, 1992; Greenwood et al., 1993; Hartley and Kieley, 1995; Hartley et al., 1990; Hasher and Zacks, 1979; Iarocci et al., 2009; Lien et al., 2011; Rabbitt and Vyas, 1980; Tales et al., 2002; Waszak et al., 2010). Some studies even indicate that the influence of peripheral non-predictive cues is larger (Langley et al., 2011a,b; Lincourt et al., 1997; Poliakoff et al., 2007) and more sustained (Langley et al., 2011a) for older compared to younger adults. This enhanced involuntary exogenous orienting has been interpreted as reflecting deficits in the top–down processes responsible for inhibiting involuntary orienting (Olk and Kingstone, 2015; West, 1996). This implies that for symbolic predictive cues eliciting endogenous orienting, older adults should show an opposite pattern. Indeed, there is evidence suggesting that endogenous orienting may be compromised by aging (Brodeur and Enns, 1997; Greenwood et al., 1993). For instance, in a task that requires one to override the desire to look towards a suddenly onsetting stimulus, and to instead look in the opposite direction, older adults fail at a rate far greater than younger adults (Bojko et al., 2004; Nieuwenhuis et al., 2000; Olk and Kingstone, 2009). Relatedly, Juola et al. (2000) report that older adults have difficulty overriding invalid sudden onset peripheral cues to utilize prior and generally valid central cues. Thus, older adults' decline in executive inhibitory functions may affect their ability to balance between exogenous and endogenous processes to achieve optimal orienting performance.

Not all studies support this proposed categorical dissociation. Some studies do not report decline in aging of top-down orienting processes (see discussion in Maylor et al., 2011; Slessor et al., 2014), and others failed to find age-specific dissociations at all (e.g., Yamaguchi et al., 1995, who also report age equivalence in amplitudes of associated contralateral attention shift-related negativity and N1 enhancement in ERPs), or indicated that differences could be attributed to general slowing (Folk and Hoyer, 1992; Lincourt et al., 1997; Olk and Kingstone, 2015). Inconsistencies regarding endogenous orienting in aging may be a function of the nature of the cues employed. Folk and Hoyer (1992) found that cues that were physically larger and contained irrelevant spatial information produced significant cueing effects for older adults, whereas smaller, simple symbolic cues did not. In contrast, variations in the nature of the cue had little effect on the performance of younger adults. Hence, it is possible that while the efficiency of endogenous shifting of attention itself is preserved with advancing age, the efficiency of processing symbolic cues is subject to age-related decline.

This notion is supported by studies using gaze cues, considered to be easily processed due to extensive past experience (Ristic and Kingstone, 2006) or overlearned associations (Brignani et al., 2009). Although cue processing in these cases should be simple

Table 1
Major representative studies of attentional orienting in aging, indicating manipulations of factors leading to exogenous and endogenous orienting, and expression of inhibition of return (IOR).

Exogenous Cueing

Study	Cue type	SOA	Task	Aging effect	Key findings
Folk and Hoyer (1992) – Exp.1	Peripheral – 100% valid or 100% invalid	50–250	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Greenwood et al. (1993)	Peripheral (non-predictive)	200, 500, 2000	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Greenwood et al. (1993)	Peripheral (non-predictive)	200, 500, 2000	Discrimination	No	Equivalent cueing and SOA effects for older and younger adults
Olk and Kingstone (2015)	Peripheral (non-predictive)	100, 450, 800	Detection	No – when controlling for general slowing	Equivalent cueing and SOA effects for older and younger adults
Iarocci et al. (2009)	Peripheral (non-predictive)	100, 800	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Waszak et al. (2010)	Peripheral (non-predictive)	100	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Olk and Kingstone (2015)	Peripheral (predictive)	100, 450, 800	Detection	No – when controlling for general slowing	Equivalent cueing and SOA effects for older and younger adults
Langley et al. (2011a) – Exp. 1	Peripheral (non-predictive)	100, 300, 600, 1000	Detection – cue presented until participants response (overlap with target)	Yes	Facilitation effects were prolonged in duration for older participants in the short SOA's (present at 300 ms for older but not younger adults)
Langley et al. (2011a) – Exp. 2	Peripheral (non-predictive)	100, 300, 600, 1000	Detection – cue presented briefly	Yes	Cueing differences between the age groups, but no interaction with SOA
Hartley and Kieley (1995)	Peripheral (predictive)	150, 350	Detection	Yes	Larger cueing effects for older adults but no interaction with SOA
Muiños et al. (2016) – Exp. 2	Peripheral (predictive)	250, 500, 1000, 1500, 2000, 2500	Detection	No	Validity effects emerged later in OA and latest in oldest-old (M = 85 y)
Hartley and Kieley (1995)	Peripheral (predictive)	150, 350	Discrimination	No	Equivalent cueing and SOA effects for older and younger adults
Faust and Balota (1997)	Peripheral (predictive)	100, 800	Detection – cue presented until participants response (overlap with target)	Yes	Cueing effects for the 100 ms SOA were larger for older compared to younger adults
Madden (1990)	Peripheral (a cursor below the target's location)	50–183	Discrimination with distractors and the cue remains until the target appears	Yes	The buildup of attention over the SOA was slower for older adults than for young adults – only in the presence of distractors
Lincourt et al. (1997)	Peripheral (non-predictive)	100, 150, 200, 250, 300	Discrimination	Yes	For younger adults, cueing effects appeared only at an SOA of 200 ms; for older adults, cueing effects appeared at 150 ms SOA and continued to develop as SOA increased
Baxter and Voytko (1996) [rhesus monkeys]	Peripheral (non-predictive)	200, 500, 900, 1100	Localization	No	For both age groups facilitation was observed only for SOA of 200 ms

Endogenous Cueing

Study	Cue type	SOA	Task	Aging effect	Key findings
Hartley et al. (1990) – Exp. 2	Central (predictive arrow)	100–500	Go/No-Go task	Yes	Older adults demonstrated larger costs and benefits.
Olk and Kingstone (2015)	Central (predictive arrows)	100, 450, 800	Detection	No – When controlling for general slowing	Equivalent cueing and SOA effects for older and younger adults
Olk and Kingstone (2015)	Central (predictive numbers)	100, 450, 800	Detection	No – When controlling for general slowing	Equivalent cueing and SOA effects for older and younger adults
Folk and Hoyer (1992) – Exp. 2	Central (predictive arrows)	50–250	Detection	Yes	Older adults did not use the spatial information given by the arrow cue
Folk and Hoyer (1992) – Exp. 3	Central (large arrow heads outside the center box)	50–250	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Langley et al. (2011a)	Central (predictive arrows)	100, 300, 600, 1000	Detection – cue presented until participants response (overlap with target)	Yes	Only older adults demonstrated facilitation effects at 300 ms SOA

Table 1 (*Continued*)

Endogenous Cueing

Study	Cue type	SOA	Task	Aging effect	Key findings
Iarocci et al. (2009)	Central (predictive arrows)	100, 800	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Greenwood et al. (1993)	Central (predictive arrows)	200, 500, 2000	Detection	No	Equivalent cueing and SOA effects for older and younger adults
Greenwood et al. (1993)	Central (predictive arrows)	200, 500, 2000	Discrimination	Yes	RT costs and benefits increase with age only for SOAs greater than 200 ms
Langley et al. (2011a) – Exp. 1	Central (non-predictive arrows)	100, 300, 600, 1000	Detection – cue presented until participants response (overlap with target)	Yes	Facilitation effects were prolonged in duration for older participants in the short SOA's (present at 300 ms for older but not younger adults)
Langley et al. (2011a) – Exp. 2	Central (non-predictive arrows)	100, 300, 600, 1000	Detection – cue presented briefly	Yes	There were cueing differences between the age groups but no interaction with SOA
Lincourt et al. (1997)	Central (predictive arrows)	100, 150, 200, 250, 300	Discrimination	No	Age difference in cueing effects only evident at SOA of 150 ms. However, general slowing explained a large part of the variance.
Curran et al. (2001)	Central (predictive arrows)	795	Discrimination	No	Cueing and SOA effects showed the same pattern for older and younger adults when estimated proportionally to overall response time
Brodeur and Enns (1997)	Central (predictive arrows)	133–800	Discrimination	Yes	Older adults needed more time to use the cue – displaying cueing effects only at long SOAs

IOR

Study	Cue type	SOA	Task	Aging effect	Key findings
Langley et al. (2011a) – Exp. 1	Peripheral (non-predictive)	100, 300, 600, 1000	Detection – cue presented until participants response (overlap with target)	Yes	IOR effects smaller for older adults
Langley et al. (2011a) – Exp. 2	Peripheral (non-predictive)	100, 300, 600, 1000	Detection – cue presented briefly	Yes	IOR effects smaller for older adults
Langley et al. (2011a) – Exp. 1	Peripheral (non-predictive) multiple cues	500	Detection – cue presented briefly	NO	Similar vector averaging in IOR effects for older and younger adults
Poliakoff et al. (2007)	Peripheral (non-predictive)	1400, 1800	Detection	Yes	IOR effects larger for older adults
Faust and Balota (1997)	Peripheral (non-predictive)	100, 800	Detection – cue presented until participants response (overlap with target)	No	Equivalent IOR effects for older and younger adults
Hartley and Kieley (1995)	Peripheral (non-predictive)	450, 750	Detection	No	Equivalent IOR effects for older and younger adults
Hartley and Kieley (1995)	Peripheral (non-predictive)	450, 750	Discrimination	No	Equivalent IOR effects for older and younger adults

For cue type, Peripheral = a cue appearing at a possible target location; Central = information-bearing cue appearing at a different location than the target. SOA – stimulus onset asynchrony; IOR – inhibition of return.

and effortless, several studies indicate a decline in such cueing effects as people age (Slessor et al., 2014; Slessor et al., 2010; Slessor et al., 2008). These findings have been associated with age-related decline in the ability to process social cues (Phillips et al., 2011; Ruffman et al., 2008; Slessor et al., 2007). This suggests that the decline in gaze-cues orienting is due to a decline in the interpretation of the social aspects of the cue (Slessor et al., 2008, 2010, 2014). This idea is further supported by indications an own-age-of-face bias for older adults under specific conditions (Bailey et al., 2014; but see Slessor et al., 2010). Interestingly, non-predictive or short SOA (100 ms) gaze cues, or non-social cues (such as arrows), rarely lead to age-related orienting difference (Gayzur et al., 2014 (except for old–old participants); Langley et al., 2011a; Slessor et al., 2014; Experiment 3). Similarly, in Bailey et al. (2014), gaze cueing by older adults was found to interact in a complex fashion with portrayed age, the emotional valence of the gazing faces, and perceptual liminality: age differences in subliminal gaze cues were smaller than in supraliminal gaze cues. Taken together, these findings support the possibility that the age-related decline in endogenous orienting is a function of the decline in the efficiency of cue processing, rather than in orienting itself.

In paradigms using multiple cue types, such as the ANT, there is a related possibly confounding factor that might be responsible for aging effects on RT. Since the ANT family of attention tests employ not only spatial cues, but also space-neutral double cues, used for testing alerting, older adults may take longer to acquire the cue-value of the double cue. This slower processing may lead to training effects, such that initially the double cues are less effective or even confusing, but subsequently become more effective in enhancing preparation processes and readiness to respond (Jennings et al., 2007). As we will explain below, the double cue condition may provide a baseline for estimating orienting benefits of valid cues and reorienting costs following invalid cues. For this reason (among others), in studies of attention and other cognitive functions in aging it may be valuable to inspect not only grand mean RTs of a condition, but also the component means of individual experimental blocks.

3.3. Cue-target stimulus onset asynchrony (SOA)

Another explanation for the inconsistencies in findings regarding the influence of aging on the orienting of attention (both endogenous and exogenous) relates to stimulus onset asynchrony (SOA): the time interval between the onset of the cue and the onset of the target that follows (Posner, 1980). At short SOAs, attention is captured exogenously by physical cue features; at longer SOAs, attention can be directed endogenously by expectations resulting from interpretation of a symbolic cue (Müller and Rabbitt, 1989; Stoffer, 1993). Accordingly, exogenous effects tend to be maximal at shorter SOAs, while endogenous effects tend to be maximal at longer SOAs (Chica et al., 2014).

When the task involves statistically predictive symbolic cues, facilitatory effects of endogenous orienting are observed only with sufficiently long SOAs, which afford participants enough time to interpret the information provided by the cue, and orient attention accordingly. The amount of time necessary depends on the type of cue (and can reach as long as 600 ms) (Chica et al., 2014). When the task involves peripheral non-predictive cues,[1] cueing effects are observed at SOAs as short as 50 ms. However, they are not consistently observed at SOAs longer than 300 ms. Depending on the task involved, at SOAs longer than 300 ms responses may show a reverse pattern (i.e., they may actually be slower at the cued location than at the uncued location), a phenomenon known as Inhibition of Return (IOR; Chica et al., 2006; Lupiáñez et al., 1997, 2006; Posner and Cohen, 1984). IOR is mostly observed with peripheral non-predictive cues (Posner and Cohen, 1984; Klein, 2004; Rafal et al., 1989; but see Chica et al., 2006). The IOR effect has been explained by several theories, including perceptual and motoric explanations (Berlucchi, 2006; Chica and Lupiáñez, 2009; Gabay et al., 2012; Lupiáñez et al., 2013; Martín-Arévalo et al., 2013; Smith and Schenk, 2012), as well as a mechanism responsible for avoiding the re-inspection of previously attended locations (Klein, 2000; Maylor, 1985; Posner et al., 1985; Posner and Cohen, 1984). Interestingly, peripheral cues that are statistically predictive do not elicit IOR (see Chica and Lupiáñez, 2009; Chica et al., 2006). This is explained by the notion that these cues do cause IOR (as peripheral non-predictive cues) but this process is followed by endogenous orienting to the cued location due to the cues' predictive nature (Chica et al., 2006).

The influence of the interval provided for cue processing (i.e., the SOA) is of special importance when considering the effects of aging on orienting (see studies listed in Table 1). This is most clearly the case for the general slowing theory of age-related cognitive changes (Cerella, 1990; Myerson et al., 1990; Salthouse, 1996). According to this account, manipulating the SOA should have a greater impact on older participants. Interestingly, this does not seem to influence exogenous orienting, even at short SOAs (100 ms) (Baxter and Voytko, 1996; Folk and Hoyer, 1992; Greenwood et al., 1993; Hartley et al., 1990; Olk and Kingstone, 2015). The IOR phenomenon commonly observed when peripheral non-predictive cues are used with long SOAs shows a somewhat less consistent pattern of findings, with most studies indicating no age influences on the magnitude of the IOR effect (Faust and Balota, 1997; Hartley and Kieley, 1995; McCrae and Abrams, 2001; Pratt and Chasteen, 2007), but others reporting that under specific conditions IOR is sensitive to age influences (Langley et al., 2001; Poliakoff et al., 2007). These conditions include the complexity of task to be performed (McLaughlin et al., 2010), the use of varied SOAs (Castel et al., 2003; Langley et al., 2001; Muiños et al., 2016), the time course for the diminishing of the effect (Langley et al., 2007), and the persistence of the non-informative cue until the target appearance (Langley et al., 2011a). In the case of onset cues in multiple display locations, older and younger adults display similar patterns of vector averaging of cues in their IOR, which is taken as indicating that age-related depletion may not apply to all aspects of inhibitory resources (Langley et al., 2011a,b). This notion is supported by studies integrating IOR with other stimulus-inhibitory processes. In young adults, IOR reduces Stroop effects (Vivas and Fuentes, 2001) and may reverse flanker and semantic priming effects (Fuentes et al., 1999), that involve stimuli in the inhibited location; this is attributed to inhibitory tagging of those stimuli. Langley et al., 2005 found that while IOR itself was not affected by age, such inhibitory tagging was evident only for younger adults. They conclude that inhibition cannot be viewed as a single process comprehensively affected by age.

Age-related deficits have often been observed for endogenous orienting (Brodeur and Enns, 1997; Folk and Hoyer, 1992; Greenwood et al., 1993; Madden, 1990; Olk and Kingstone, 2015), with some indication for larger effects at short SOAs (Hartley et al., 1990). However, numerous studies have indicated that age has little or no effect on endogenous orienting, even at shorter SOAs (Curran et al., 2001; Faust and Balota, 1997; Greenwood et al., 1993; Hartley et al., 1992, 1990; Hartley and McKenzie, 1991; Tales et al., 2002). This discrepancy can be resolved by controlling for age-related general slowing (see Olk and Kingstone, 2015). That type of control has been shown to reduce the interaction between age and endogenous orienting effects, with one study indicating that general slowing

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[1] That is, cues that do not predict the target location overall (a 1:1 ratio of valid and invalid trials), but that in the specific trial in question is valid.

contributed to as much as 93% of the age-related variance (Lincourt et al., 1997).

3.4. Post-Orienting task factors

An interesting body of findings indicates that the effects of visuo-spatial orienting are modulated by non-spatial factors, such as the specific task to be performed with the target stimuli after the orienting process has been completed. Orienting paradigms incorporate a variety of tasks requiring participant responses, which may differ in complexity of processing and response requirements. These include discrimination conflict (e.g., flanker tasks), location report, and Go/No-go challenges (Chica et al., 2014; task characteristics of aging-orienting studies are included in Table 1). Cueing effects have been reported to be a function of the interaction between task complexity and SOA.

Detection and localization tasks were frequently used in early orienting studies (Posner, 1980). In these paradigms, statistically non-predictive peripheral cues commonly fail to produce facilitation in the valid trials, even at short (<300 ms) SOAs (Chica et al., 2014) or require specific conditions [brief SOAs (50 ms) and long cues (150 ms)] to do so (Collie et al., 2000). Moreover, even when these cues are predictive (i.e., entraining endogenous and exogenous orienting together), facilitation effects are not as stable, nor as large as commonly assumed (Chica and Lupiáñez, 2009; Chica et al., 2006). On the other hand, the phenomenon of IOR is consistently found for simple detection and localization tasks (Gabay et al., 2012; Klein, 2000; Tanaka and Shimojo, 1996; Tassinari et al., 1994). Later studies involved more complex tasks, such as discrimination conflict and Go/No-go tasks. For such tasks, both exogenous and endogenous orienting are typically observed at short SOAs (<300 ms; Chica et al., 2006, 2014). Interestingly, exogenous orienting in this type of tasks demonstrates facilitatory effects that are typically larger compared to those observed in detection tasks (Chica et al., 2014). Additionally, the range of SOAs commonly impacts the magnitude of cueing effects in discrimination conflict tasks, but not in simple detection tasks (Milliken et al., 2003). IOR is observed in discrimination conflict and Go/No-go tasks only at long SOAs (>700 ms, Lupiáñez et al., 2001), or is sometimes completely absent (Funes et al., 2007; Lupiáñez et al., 1997).

This pattern of findings, indicating that orienting effects in young adults are smaller in simple detection compared to discrimination conflict tasks, has been explained as resulting from a reduced need for focal attention in the detection task. However, some studies indicate that at relatively short SOAs (200 ms) effects are greater in the detection task than in the discrimination task, suggesting that orienting proceeds faster in detection tasks than in discrimination tasks (Greenwood et al., 1993). Importantly, the more complex tasks (discrimination, Go/No-go) involve executive functions such as inhibition, known to decline in aging (as described earlier). Orienting paradigms involving tasks of different levels of executive complexity may thus show different patterns of results across the lifespan.

Taking all of these considerations into account leads to a prediction of a triple interaction between orienting, task complexity, and age, which has rarely been tested. An example of such a study is the direct comparison between detection and discrimination tasks performed by Greenwood et al. (1993). They found that RT costs and benefits increased with age only for SOAs greater than 200 ms, with central cueing, in the discrimination task. This result implies that task type influences age-related differences only under extremely specific conditions. Clearly, further research is required in order to understand the impact of task complexity on orienting when aging is involved.

3.5. Orienting benefits and costs

As stated earlier, attentional orienting involves processes such as disengaging attention from its current focus, shifting attention, and engaging attention (Posner et al., 1984). While shifting and engaging attention are part of every orienting process, disengagement is required only in cases in which attention was already focused and must be shifted to a new location (Corbetta et al., 2000; Corbetta et al., 2008; Fan et al., 2009). Accordingly, studies typically measure the *benefits* of shifting attention as well as the *costs* of disengaging attention from its current focus. The benefits and costs (also termed orienting effects, cueing effects, or orienting vs. reorienting) are manipulated by the cues used in the paradigm. Generally, benefits are expressed by *RT double cue* minus *RT valid cue,* while costs involve *RT invalid cue* minus *RT double cue* (Fan et al., 2009). In studies employing gaze cues, the double cue is replaced by a neutral gaze facing forward (e.g. Slessor et al., 2014). It is now well established that benefits and costs of attentional orienting are not merely two aspects of the same phenomenon, but rather involve different mechanisms based in different brain areas (Corbetta et al., 2000, 2008; Corbetta and Shulman, 2002; Downar et al., 2001, 2002). It is therefore possible that age will have a differential impact on costs and benefits, as aging may not influence all brain regions to the same extent (see below).

Surprisingly, studies comparing age influences on benefits and costs are rare, and even when the required cues for measuring costs and benefits (i.e., valid, double or neutral, invalid) are manipulated, the relevant analysis is not provided (Greenwood et al., 1993; Fernandez-Duque and Black, 2006). Instead, most aging studies test validity effects (i.e., *RT invalid cue* minus *RT valid cue*), which does not enable differentiation between age influences on benefits and costs. Even studies indicating no interaction between age and validity effects (e.g. Fernandez-Duque and Black, 2006; Nissen and Corkin, 1985) cannot rule out the possibility that there is a different proportion of costs and benefits in older age summing up to the same validity effect. Moreover, several studies do report an age-validity interaction in specific conditions (e.g. Curran et al., 2001; Greenwood et al., 1993; Hoyer and Familant, 1987). In these studies it is unclear whether the interaction is due to different costs, benefits, or both. The few studies that directly tested this interaction (Slessor et al., 2014; Tellinghuisen et al., 1996) have provided contradictory results. Slessor et al. (2014) found reduced benefits and increased costs for older participants when using predictive gaze cues. On the other hand, Tellinghuisen et al. (1996) indicated similar effects of costs and benefits for older and younger participants in a paradigm employing predictive arrow cues. However, the SOAs used in this experiment were quite long (1000 or 2000 ms), possibly eliminating aging effects. It is therefore yet to be determined whether aging has a differential influence on orienting costs and benefits. However, we note that some indication for disengagement decline as people grow old is suggested by studies testing different age groups in later life. As will be elaborated in the next section, performance differences between young-old (65–75) and old–old participants (75–85 years) imply a subtle decline in disengagement processes (Gayzur et al., 2014; Langley et al., 2011a).

The question of whether older adults are poorer at disengaging their attention from an uncued or miscued location in order to reorient their attention to actual location of a target stimulus may be seen within a larger context of observations regarding age-related ‘stickiness’ of processing and slower disengagement from recently experienced events (Cashdollar et al., 2013). Cases of such stickiness include prolonged delay in visual discrimination responses caused by prior presentation of salient distractors (not specifically spatially distracting; Cashdollar et al., 2013); elimination of attention-related ERP responses to target letters immediately following prior target letters (i.e., profound neural correlates of attentional blink; Cona et al., 2013); and behavioral impairment in recovery from distraction in a working memory task accompanied by failure to reinstate the neural activity substrate of the target representation (Clapp et al., 2011). In all those cases, however, the disengagement difficulty is from stimuli, rather than from spatial locations; aging effects on reorienting must be investigated in their own right, with careful dissociation of such possible costs from the impact of orienting benefits. Constructing a baseline condition that is truly neutral in order to conduct chronometric subtractions characterizing orienting and reorienting is challenging, as target-location-neutral cues may have some suppressive effect on spatial orienting, but this aspect of orienting processes should not be neglected.

3.6. Orienting at different stages of later life

An interesting question is whether the age influences on attentional orienting depend on the stage of aging. In general, the age of participants in studies testing these influences ranges from 60 (Lincourt et al., 1997) to over 90 (Gayzur et al., 2014). It is possible that the age influence pattern varies non-linearly across these ages. The notion that later life cannot be viewed as a unitary developmental phase is supported by indications for cognitive and affective discrepancies between different age groups, sometimes referred to as young-old, old-old, and oldest-old (Field and Minkler, 1988; Garfein and Herzog, 1995; Hoch et al., 1994; Menec and Chipperfield, 1997).

Regarding attentional orienting tasks, these stage-of-aging effects seem to vary in accordance with the specific type of orienting required. Typically, on detection tasks involving predictive cues, performance was found to be preserved even at old–old ages (75–85 years old), with no indication for changes across adulthood (Greenwood et al., 1993; Greenwood and Parasuraman, 1994). This stability across later life is also evident for discrimination tasks which employ peripheral non-predictive cues that do not temporally overlap with the target, considered to elicit automatic exogenous orienting (Muiños et al., 2016; Waszak et al., 2010; but see Langley et al., 2011a), as well as non-predictive peripheral and central arrow cues that do temporally overlap with the target (Langley et al., 2011a). Likewise, no aging-stage effect was found on a discrimination task involving peripheral predictive cues (Greenwood et al., 1993; but see Greenwood and Parasuraman, 1994 at the 200 ms SOA). On the other hand, a difference in cueing influences is reported between old–old (75–85 y) participants and young-old participants (65–75 y) on discrimination tasks involving arrow (symbolic) predictive cues, for SOAs larger than 200 ms (Greenwood et al., 1993, 1997). This may indicate that tasks in which orienting is less automatic and requires some strategic processing component, advanced old age may impose additional time costs. Attentional orienting changes across later life are also indicated by later onset and larger effects of IOR (Langley et al., 2011a,b; Muiños et al., 2016; Poliakoff et al., 2007), as well as slower responses to invalid peripheral predictive cues, which have been interpreted as a decline in disengagement processes (Greenwood and Parasuraman, 1994; Langley et al., 2011a).

Interestingly, different age-stage patterns are reported when uninformative gaze cues are used. In this type of task, aging-stage effects interacted with SOA and exhibited different patterns as a function of temporal overlap between the cue and the target (Gayzur et al., 2014). When there was an overlap between the cue and the target, old–old adults showed no cueing effects at a short SOA (100 ms), while young-old participants did show such effects. When there was no temporal overlap between the cue and target, all age groups showed cueing effects of the same magnitude, even at the short SOA (100 ms). The interaction between aging-stage influences and cue overlap is attributed to a difficulty in disengaging attention from the gaze cue. Reducing cue-target overlap, and short cue duration in the no-overlap condition, are thought to encourage disengagement from the gaze cue, and hence to enable validity effects even for short cue-target intervals. Complementarily, in the overlap condition, old–old adults were not able to disengage rapidly from the gaze cue as it remained on the screen, and therefore oriented less effectively (Gayzur et al., 2014).

In summary, research has indicated that the stage of aging influences orienting efficiency under specific conditions. While further research is required for determining the extent of the phenomenon, current data suggests that the main factor underlying these differences is a subtle decline in disengagement processes.

4. Higher-order orienting processes

4.1. Object-based orienting

In space-based orienting paradigms, attention is assumed to be allocated to topographic regions of the visual field (Arrington et al., 2000; Egeth and Yantis, 1997; Goldsmith, 1998). However, attention may also be directed towards specific coherent forms or objects, a process termed object-based orienting (Chen, 2012; Moore et al., 1998; Watson and Kramer, 1999; see Scholl, 2001 for a review). This type of orienting involves selecting objects and perceptual groups in the visual space for attentional focus (Kramer and Weber, 1999). This is in line with the view of Kahneman et al. (1992) that the visual field is initially pre-attentively segregated into perceptual units or objects on the basis of Gestalt grouping principles (Duncan, 1984; Kahneman and Treisman, 1984; Marino and Scholl, 2005; Wertheimer, 1923), such as uniform connectedness (Palmer and Rock, 1994). Attention is then employed in order to select objects from the visual array, and to process them in greater detail (see also Arrington et al., 2000). Paradigms testing object-based orienting typically involve a spatial orienting task (e.g., a cueing paradigm) in a visual space containing objects. This design allows for testing orienting to locations in space that are perceived as either belonging to the same or different objects as the preceding cue. According to space-based models of attention, as long as the distance is equal, belonging to the same or different object should have no impact on performance. Typical findings, however, indicate that target detection is faster for targets presented within the same object as the cue, as compared to targets presented within a different object, despite being the same distance from the cued location (e.g., Atchley and Kramer, 2001; Chen, 2012; Duncan, 1984; Egly et al., 1994; Kanwisher and Driver, 1992; Kimchi, 2009; Lamy and Egeth, 2002; Vecera and Farah, 1994; Soto and Blanco, 2004). While object-based attention has recently been demonstrated to be less predominant than space-based attention (Pilz et al., 2012), space-based and object-based components of attention may interact in influencing performance (e.g., Atchley and Kramer, 2001; Goldsmith, 1998; Humphreys et al., 1996; Lavie and Driver, 1996; Soto and Blanco, 2004).

The notion of object-based orienting is relevant for understanding attention in aging, as some studies indicate increasing deficits in perceptual organization as people grow old (Bian and Andersen, 2008; Gilmore et al., 1985; Madden et al., 1996; Plude and Hoyer, 1986; Staudinger et al., 2011). Such a decline in perceptual organization could lead to smaller effects of object-based orienting. Notably, however, in the very few studies which directly tested aging effects on object-based orienting, it was found to be insensitive to healthy aging (Groth and Allen, 2000; Kramer and Weber, 1999). The only indication of age influences on spatial-object-based orienting comes from object-IOR studies. In these studies, target location is cued either by a spatial cue or by integrated object and spatial cues. While young adults show increased IOR effects when cues are based on both objects and spatial information, older adults are not sensitive to the difference between the cues (McAuliffe et al., 2006). Similarly, McCrae and Abrams (2001) found that older adults exhibited reduced object-based IOR in moving object displays. It remains to be determined whether object-based orienting processes are preserved in aging in a wider range of circumstances and more ecological conditions.

4.2. Multi-feature visual search

The process of detecting, orienting to, and identifying salient stimuli in a complex environment has been modeled using the visual search paradigm. In this task, participants are instructed to report the presence or absence of a specific target presented among distractors. Performance on the visual search task is measured by response time for target identification, which is reported as function of the number of distractors (Duncan and Humphreys, 1989; Treisman and Gelade, 1980; Wolfe et al., 1989). Numerous studies have indicated two patterns of performance. When distractors are homogenous and differ from the target by a single feature (color, shape, size, etc.) performance is not influenced by the number of distractors; this condition is generally termed parallel search or feature search. In contrast, when the target shares features with the distractors, and is defined by a particular conjunction of those features, search becomes less efficient, and RTs are influenced by the number of distractors; this condition is termed serial search or conjunction search. These findings are commonly explained by Feature Integration Theory (FIT; Treisman and Gelade, 1980; Treisman, 1991; Wolfe, 2014; but see Verghese, 2001). According to this theory, visual perception is based on topographically organized feature maps. The visual search is based on two stages, the first being a pre-attentive stage in which features are identified in parallel in the feature maps. If a target is not isolated based on the single feature maps in this parallel stage, a second search is initiated. In this stage, attention is serially focused on individual items in order to create a conjunction of features from the different feature maps. This process requires integration of information from multiple brain regions in order to represent the target (i.e., features are 'bound' at a higher stage of the ventral visual object identity pathway by conjoining the inputs from lower-level visual areas; Wei et al., 2011). The integration of features requires a master map of spatial locations, where information regarding each item can be integrated according to its location (Treisman, 1988; Treisman and Gormican, 1988; Treisman and Sato, 1990).[2]

The impact of the nature of target and distractor features and the role of spatial maps emphasized by FIT seem at first glance to be orthogonal to the processes of focusing and shifting spatial attention elucidated above. Visual search paradigms pre-define the identity of the target, and have participants inspect the spatial array to locate it; in contrast, orienting paradigms pre-define the location of the target, and have participants focus on its assumed location to identify it. However, the analysis of a visual scene is based on mechanisms responsible for focusing and shifting attention from one location to another (Corbetta and Shulman, 1998). For example, feature search is based on attention capture by the salient target ("pop out"), and requires shifting attention from current fixation to the target. The involvement of attention shifting in feature search is supported by findings indicating that valid spatial cueing facilitates responses in feature search, and that spatial eccentricity slows them (Carrasco and Yeshurun, 1998; Greenwood and Parasuraman, 1999; Gruber et al., 2013). In conjunction search, attention must be disengaged, shifted and engaged voluntarily, moving from item to item until the target is found (a similar account is offered by Trick and Enns, 1998).

Supporting this conceptualization are studies that indicate that patients with parietal lobe lesions who exhibit unilateral neglect have difficulty with both conjunction and feature search (Behrmann et al., 2004; Jelsone-Swain et al., 2012; but see earlier studies, such as Aglioti et al., 1997). Interestingly, the effect of lesions associated with neglect on conjunction search seems to be quantitative further slowing of the type observed in healthy participants, while in feature search, such brain damage seems to cause a qualitative shift in search strategy from parallel to a slowed serial search, indicating impairment in attentional capture (Behrmann et al., 2004). This pattern supports the involvement of attentional capture in feature search.

FIT and attentional orienting paradigms seem to provide complementary views of visual search. Taken together, they posit that visual search may involve feature binding, selection of targets among distractors, and shifting and engaging attention at different locations in space. Accordingly, Greenwood and Parasuraman (1999) suggested that the attentional processes involved in visual search are defined by the size and scale of attentional focus and its interaction with attention shifting. The efficiency of the repeated shifts required for conjunction search involves the ability to adjust the size or scale of attentional focus.

When evaluating the influences of aging on visual search, it is important to relate to all these aspects independently. Several studies have reported an age-related decline in visual search abilities (e.g., Amenedo et al., 2012; D'Aloisio and Klein, 1990; Madden, 2007; Madden and Whiting, 2004; Plude, 1990; Plude and Doussard-Roosevelt, 1989; Rabbitt, 1965). This decline is clearly evident in conjunction search, but is rarely found in feature search (Cosman et al., 2012; Humphrey and Kramer, 1997; Madden, 2007; Plude, 1990; Trick and Enns, 1998; Whiting et al., 2005). Both FIT and the attention orienting accounts may explain the differential effects of age on the two types of visual search. The FIT approach may propose a decline in the ability to perform feature integration and to mark old objects (Kramer and Atchley, 2000; Plude and Doussard-Roosevelt, 1989), while an orienting approach would be more concerned with a decline in the ability to shift attention in space (Connelly and Hasher, 1993; Hartley et al., 1990; Madden, 2007), possibly specifically the disengagement part of that process (D'Aloisio and Klein, 1990). The abovementioned generally efficient performance of feature search by older adults is notable, as it indicates that attentional capture by salient stimuli that enables performance of this type of task is preserved in old age (but see Owsley et al., 2000). In contrast, as stated above, numerous studies demonstrate an age-related decline in conjunction search (but see Kramer et al., 1996). This decline is commonly attributed, *inter alia*, to reduced ability to integrate features (Foster et al., 1995; Treisman and Gelade, 1980), deficient distractor inhibition or target activation (Folk and Lincourt, 1996; Madden et al., 1996; Treisman and Sato, 1990; Wolfe, 1994), or reduced control of spatial attentional focus, specifically in scale adjustments (Greenwood and Parasuraman, 1999, 2004; Greenwood et al., 1997). Nevertheless, it is also possible that the repeated need to shift attention from one stimulus to another is the origin of this age-related decline. Several studies have tried to tease apart different processes underlying visual search (Nobre et al., 2003). For example, Trick and Enns (1998) focused on spatial shifting and feature binding aspects. They showed that in the absence of spatial uncertainty, feature binding abilities are not affected by age (compare the finding of D'Aloisio and Klein (1990) of an aging-related deficit in visual search even when the integration of features is not required). This was also the case for feature binding when the spatial location of the target was

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[2] An alternative approach is that types of visual search are not dichotomous, but rather describe a continuum of efficiency (Wolfe, 2014). Our comments on the relationship between classic visual search paradigms and orienting paradigms are relevant to those approaches as well.

manipulated, as long as it wasn't accompanied by distractors. Aging impacted performance (yielding greater slowing) only for conjunction search with multiple distractors. This was interpreted by Trick and Enns (1998) as indicating a decline in shifting of attention, as a larger set size inherently requires more shifting. Madden and colleagues examined older adults' performance on letter search tasks with valid and invalid location cues differing in types of distractors, and conclude that age-related changes in the shifting of focused attention in visual search are minimal except when the processing of nontarget information is required (Madden, 1992; Madden et al., 1994). Similarly, McLaughlin and Murtha (2010) found that precueing a section of the display in a conjunction search task improved older adults' performance only when it reduced the number of distractors to be considered. However, it must be noted that a larger set size also inherently requires more feature binding operations, so that the cause of the aging effects in visual search remains to be determined.

A case of visual search that involves orienting and re-orienting in a different sense is contextual cueing (Chun and Jiang, 1998). In this paradigm, conjunction search is performed on multiple trials, with the target seemingly randomly placed within the search array. However, on a subset of trials, the target-distractor arrays are repeated a number of times. Despite their later inability to discriminate between novel and repeated search arrays (Chun and Jiang, 2003), participants are more efficient in locating targets in the repeated arrays. This effect may be understood as reflecting implicit memory-guided spatial orienting affecting object-guided visual search. Notably, despite occurring in the absence of awareness of distractor array identity, this effect is dependent on hippocampal (Chun and Phelps, 1999) or medial temporal lobe (Manns and Squire, 2001) integrity. Accordingly, it might be expected to be adversely affected by aging. However, several studies have indicated such effects are intact in healthy aging, both for simple target location detection (Merrill et al., 2013) and for target discrimination (Howard et al., 2004). Interestingly, Howard and colleagues report that older adults who exhibited awareness that some arrays were repeated did not show contextual cueing effects. They interpret this finding as reflecting greater costs of a strategic approach to the task in older participants. However, the disappearance of the effect seems to result from the longer response times to new displays in the unaware condition (Fig. 4 in Howard et al., 2004), suggesting that older adults might have had intact strategic control, but greater re-orienting costs for new displays in the absence of a controlled search strategy.

4.3. Temporal orienting

In attentional assessment paradigms employing a predictable temporal structure of events, such as a fixed SOA, participants may develop endogenous temporal expectations based on learning the overall rhythm of presentation, which have been shown to be a powerful attentional cue (Besle et al., 2011; Davranche et al., 2011; Miniussi et al., 1999; Nobre and Rohenkohl, 2014; Rohenkohl and Nobre, 2011; Stefanics et al., 2010; van Ede et al., 2011; Vangkilde et al., 2013), above and beyond the trial-based temporal cues used for testing alertness (Klein and Lawrence, 2011). Learning the time interval structure of critical events can engender endogenous alerting at the point in time at which attention is required in order to optimize behavior (Correa et al., 2005; Coull and Nobre 1998; Cravo et al., 2013; Griffin et al., 2001). Some researchers have proposed that spatial orienting can be directed according to temporal information independently of the availability of spatial cues (Posner and Boies, 1971; Posner and Petersen, 1990; see also Weinbach and Henik, 2012; Weinbach et al., 2014) while others have reported a strong interaction between temporal and spatial expectations (e.g., that temporal cues significantly improved performance on valid trials only; Doherty et al., 2005; Griffin et al., 2001; Rohenkohl et al., 2014; but see Rohenkohl et al., 2011).

The aforementioned findings suggest that aging influences on spatial orienting may be mediated by aging effects on temporal orienting. The notion that temporal orienting may be sensitive to the effects of age stems from indications of age-related deficits in expectation-driven neural processes (Bollinger et al., 2011; Pincham et al., 2012; Vallesi et al., 2009). Along these lines, Zanto et al. (2011) found that while younger adults used temporal cues to enhance performance in detection and discrimination tasks, older adults could not benefit from this predictive information. This behavioral finding was supported by alterations in pre-target neural processing, as expressed in cue-induced alpha power lateralization that was observed in younger, but not older adults. This type of age difference in neural processing is found even when behavioral performance is similar (Hong et al., 2015), suggesting that older adults recruit additional control processes to improve task performance that compensate for their diminished sensitivity to temporal expectations.

Young adults' superior ability to benefit from temporal information in attentional orienting tasks may explain some of the inconsistencies in aging effects noted in this review, especially when fixed SOAs are used. Most of these studies do not thoroughly consider the profound impact of the temporal information provided by fixed SOAs or predictable temporal structure, and its varied influences across different age groups. Future studies should take more careful note of this factor.

5. Age-related changes in the brain substrates of attentional orienting

Decline in cognitive abilities in aging is often assumed to be related to changes in various aspects of brain structure and function (Grady, 2012; Raz and Rodrigue, 2006; Reuter-Lorenz and Park, 2010; but see Salthouse, 2011). These changes include reduction in cortical gray matter volume, decrease in cortical thickness, occurrence of white matter lesions, diminution of white matter integrity, and less effective neuromodulatory systems (Grady, 2012; Lockhart and DeCarli, 2014). Although a full treatment of brain changes in aging is far beyond the scope of the current review, it is important to consider the effects of aging on the neural substrates specifically supporting attentional orienting. The following section touches briefly on some findings of anatomical and functional characteristics of the aging brain seemingly most relevant to orienting, indicating issues worthy of further investigation.

5.1. Cortical volume and thickness changes

Past cross-sectional studies of brain integrity in aging, notably the volumetric analyses derived from the Framingham Heart Study including 2200 individuals aged 30–90 (DeCarli et al., 2005), suggested that age-related cortical volume reductions are most prominent in prefrontal cortex, with differences in occipital and parietal lobes being modest and generally non-significant (Lockhart and DeCarli, 2014; Raz and Rodrigue, 2006; Sowell et al., 2003). On the basis of those trends, which accord with the frontal hypothesis of aging, one might predict that orienting aspects of attention, which strongly depend on extensive parietal substrates, might be less susceptible to aging-related changes than executive control of attention, given its predominantly frontal substrate (as noted above). However, recent evidence from longitudinal neuroimaging of the aging brain does not support the initial cross-sectional finding of selective frontal decline. One recent major longitudinal study assessed rates of cortical atrophy among 1172 cognitively healthy older adults aged 65–82 years, in two MRI scans collected over four years (Crivello et al., 2014). This study reported that parietal regions showed cortical atrophy rates comparable with those of frontal regions. Smaller studies also indicated that for age-related decline in cortical thickness (Thambisetty et al., 2010) and volume (Resnick et al., 2003), frontal and parietal regions similarly exhibited greater rates of decline than temporal and occipital lobes. Accordingly, the possibility of decline in aging in attentional functions with parietal substrates cannot be ruled out.

Given the allocation of orienting and reorienting functions to separable dorsal and ventral substrates (Corbetta et al., 2008), the question arises whether there might be neuroanatomic bases for differences in the efficacy of those functions in old age. Interestingly, Crivello et al. (2014) report greater rapidity of atrophy of the superior and inferior parietal gyri (−1.58%/year and −1.24%/year, respectively) than that of the supramarginal gyrus (−0.8%/year), the latter being implicated in reorienting of attention, as evidenced by its connection with neglect disorders (Karnath, 2015). Those differences in rates of regional atrophy suggest that differential aging effects might be found for orienting and reorienting functions. Relatedly, age-related acceleration in the decline of local cortical volume has been reported for superior parietal cortex (Driscoll et al., 2009). However, another longitudinal study (Fjell et al., 2014), based on 207 participants aged 60–91 years, reported similar annualized atrophy rates for parietal regions (superior, −0.46%; inferior, −0.42%; supramarginal, −0.43%). It is therefore difficult to derive clear predictions of differential cognitive change in components of orienting from brain aging data.

5.2. White matter changes

As attentional functions require the interactive contributions of a network of fronto-parietal brain regions and subcortical nuclei providing neuromodulatory efferents, the integrity of underlying white matter, important for functional connectivity, may be no less determinant of cognitive functions than cortical structural integrity. Indeed, separate branches of the superior longitudinal fasciculus connecting frontal and parietal regions have been assigned specific roles for ventral and dorsal fronto-parietal attention networks and the interaction between them (Thiebaut de Schotten et al., 2011). As far as changes in aging, Ziegler et al. (2010) report correlations of cognitive performance in aging with white matter integrity, but not with cortical thickness. Additionally, it has recently been demonstrated that white matter hyperintensities, reflecting ischemic pathologies in small blood vessels or other localized vascular irregularities, mediate age-related changes in a visual search task (Lockhart et al., 2014), and in other memory and executive function abilities (Lockhart and DeCarli, 2014). Notable for the current discussion is the longitudinal and cross-sectional study of differences in regional gray and white matter volumes conducted by Raz and colleagues (2005), which found significant age-related volume losses in both prefrontal and inferior parietal white matter, possibly especially relevant for the ventral attentional network.

Diffusion tensor imaging (DTI) studies provide some support for the contention that white matter integrity mediates the relationship between age and cognition (although aging itself is linked with notable decline in white matter integrity; Bennett and Madden, 2014). Using DTI, Kennedy and Raz (2009) found separable associations of decline in white matter integrity: with processing speed and working memory in anterior brain regions such as the superior frontal gyrus white matter and genu of the corpus callosum, with episodic memory in central regions such as the posterior limb of the interior capsule and the temporal stem, and with executive inhibition and task switching in posterior regions such as superior parietal and occipital white matter. Orienting functions were not assessed. Pursuant to the notion explored above that visual search tasks involve orienting processes, it is interesting to note the study of Bennett et al., 2012, who report that integrity of fronto-parietal white matter tracts (the superior and inferior longitudinal fasciculi, subserving the dorsal and ventral attentional networks, respectively) was predictive of feature and conjunction search speed for both younger and older adults, with the latter group being slower in conjunction search and exhibiting lower white matter tract integrity.

5.3. Neuromodulatory changes

Even in the absence of frank degeneration, there may be relatively early functional declines in brain processes supporting attention and other cognitive functions (Reuter-Lorenz and Park, 2010; Salthouse, 2009). These may result from declines in the efficacy of neuromodulatory systems (Li, 2013). While changes in dopaminergic signaling, particularly important for frontal regions, have been particularly noted (Klostermann et al., 2012; Störmer et al., 2012), aging is also strongly associated with declines in cholinergic activity (e.g., Dumas and Newhouse, 2011; Störmer et al., 2012), which is specifically important for the orienting of attention (Demeter and Sarter, 2013). As noted above, age-related changes in noradrenergic transmission and receptors, which may be important for the interaction of alerting and orienting functions, have also been observed (Ferrari and Magri, 2008; Lohr and Jeste, 1988; Robertson, 2013; see also Mather et al., 2015). Accordingly, age-related declines in all attentional systems might be anticipated, but it is not clear at what age decreased neuromodulation efficacy would be expected to yield behavioral effects, or to what extent there are significant individual differences in neuromodulatory decline.

5.4. Lateralization

When discussing aging effects on attentional orienting, it is important to consider the influence of more general effects, such as age-related lateralization changes. Some of the orienting functions discussed above, such as the disengagement required by reorienting, are considered to be primarily right hemisphere (RH) mechanisms (Rengachary et al., 2011). This is demonstrated *inter alia* by the phenomenon of unilateral visuospatial neglect, in which symptoms occur more frequently and severely after right as compared to left hemisphere (LH) stroke (Driver and Mattingley, 1998; Halligan et al., 2003; Harvey and Rossit, 2012; Vallar, 1998). Given neglect patients' impairments in orienting, indications of RH decline in aging affecting other functions (e.g., Lux et al., 2008) raises the question whether attentional orienting declines in older age due to such RH changes.

Some traction on this issue may be gained from studies testing age differences in the phenomenon of pseudoneglect (Bowers and Heilman, 1980). Pseudoneglect refers to the slight but systematic perceptual or visual judgment bias favoring the left visual field in healthy adults (Bradshaw et al., 1986; Brooks et al., 2014; McCourt et al., 2001; Voyer et al., 2012). This bias is attributed to RH dominance for visuospatial attention processing (Benwell et al., 2014; Cai et al., 2013; Cavézian et al., 2012; Çiçek et al., 2009; Fierro et al., 2001; Fink et al., 2001; Thiebaut de Schotten et al., 2011; Waberski et al., 2008). Although consistently found for young healthy participants, the systematic leftward bias of pseudoneglect is not always found in older populations, and in some cases is even reversed (Benwell et al., 2014; Brooks et al., 2014; Failla et al., 2003; Fujii et al., 1995; Goedert et al., 2010; Hatin et al., 2012; Loureiro et al., 2013; Nagamatsu et al., 2011; Schmitz and Peigneux, 2011; Veronelli et al., 2014; but see Brooks et al., 2011; Chen et al., 2011; McGeorge et al., 2007).

Several candidate explanations have been proposed for the absence of pseudoneglect in older adults (Benwell et al., 2014; Brooks et al., 2014) including accelerated aging-related decline in RH relative to the LH (Brown and Jaffe, 1975; Goldstein and Shelly, 1981; Lux et al., 2008; Nagamatsu et al., 2011). A decline in RH dominance may result in more symmetric visual field processing. An alternative account posits that older adults exhibit less lateralized performance since they recruit both hemispheres as a compensatory strategy. According to this model, termed Hemispheric Asymmetry Reduction in Older Adults (HAROLD; Cabeza, 2002) older brains compensate for general cognitive decline by recruiting additional neural resources, which may involve areas in the hemisphere not utilized by younger participants in a given cognitive task (Cabeza, 2002; Dolcos et al., 2002; Prakash et al., 2009; Zhou et al., 2011).

Notably, these two accounts (i.e., RH decline and HAROLD) offer different predictions regarding attentional orienting. While the RH decline account predicts different performance for left vs. right attentional orienting, as well as a general deficit in reorienting (due to the lateralization of disengagement function to RH), HAROLD predicts equal behavioral performance in both directions, and intact disengagement. Relevant to this issue, a study by Nagamatsu et al. (2011) examined the effects of orienting cues on target detection in older and younger adults, and its electrophysiological correlates. They report that the amplitude of an event-related potential (ERP) component associated with the control of visual spatial orienting (elicited by cues directing attention to the left visual field) was reduced for older adults. This was interpreted as indicating selective aging decline in endogenous orienting of attention to the left visual field. Additionally, older adults' responses for targets in the left visual field after an invalid cue were associated with delayed latency of the P1 ERP component (associated with initial sensory-evoked response in visual cortex). The authors interpret the latter finding as indicating a possible age-related difficulty in disengaging visual spatial attention from the right visual field in favor of a target in the unattended left hemifield. These findings are seen as supporting the RH decline hypothesis. However, it should be noted that in that study older adults exhibited a speed-accuracy tradeoff relative to younger adults (slower but more accurate performance), possibly indicating a strategic compensatory recruitment of additional processing resources that may have influenced their pattern of brain activity relative to younger adults, in line with the HAROLD account. Further studies regarding the right hemisphere decline vs. compensatory recruitment accounts in general may serve to explicate the abovementioned findings.

5.5. *Functional connectivity and compensatory recruitment*

Functional neuroimaging studies of attention in aging point to two issues with relevance for orienting: functional connectivity and compensatory activity. Studies of brain activation during executive attention tasks (attention to specific task-relevant cues: Madden et al., 2010; stimulus class expectancy in a working memory task: Bollinger et al., 2011) have noted lower indices of functional connectivity between dorsal prefrontal and parietal attention-related regions in older adults. This is interpreted as suggesting that weakened prefrontal-parietal functional connectivity may account for the reduced attention of older adults to stimuli in the environment (Grady, 2012). A recent study examining the resting-state functional connectivity within a network of brain regions associated with a modified Posner paradigm orienting task (detection of target after a predictive central arrow cue) reported no significant aging effect on the task-related activation pattern in a distributed fronto-parietal network, and very minor differences in resting-state functional connectivity in task-relevant areas (Li et al., 2015).

Complementarily, several hemodynamic imaging studies of cognition in aging suggest that older adults may sometimes exhibit performance on a particular task equivalent to that of younger adults through the recruitment of additional brain resources, i.e., functional compensation (Cabeza et al., 2002; Grady, 2012; Reuter-Lorenz and Park, 2014), as would be predicted by the HAROLD model mentioned above. This has been found especially at low or moderate levels of task difficulty (Reuter-Lorenz and Cappell, 2008), suggesting that orienting must be tested across levels of difficulty to detect possible age-related differences. Interestingly, compensatory recruitment features in the report of Vallesi et al., 2011 that older adults engaging fronto-parietal attention-related regions to a greater extent than younger adults committed fewer errors in a challenging phase of a Go/No-go task. Huang et al. (2012) report additional parietal activations in older adults contralateral to loci activated in younger adults, which were related to relatively better performance in two Stroop-like executive attention tasks, indicating that parietal areas may be involved in compensatory processes; it remains to be determined whether this would be the case for orienting aspects of attention as well. Also relevant is the study by Geerligs et al. (2014), who required participants to respond differentially to target letters in some locations and to non-target letters or targets in other locations. They report that for older adults, increases in activity during distractor trials (target letters in locations for which responses were the same as for non-target letters) in dorsal frontal and parietal regions, and functional connectivity between those regions and sensorimotor areas, were related to response accuracy. The authors interpret this finding as related to orienting of attention to the distractors. However, in that study (as in many others), older adults responded much more slowly to distractors in favor of accuracy, and it is unclear whether the relative increases in activity are simply a function of the longer processing time in a task that requires spatial orienting. Relatedly, in an ERP study of target detection with conditions designed to reflect pop-out (feature) vs. effortful (conjunction) search, older adults exhibited a parietal-to-prefrontal shift in the distribution of the P300 target detection-related component for both types of search (Li et al., 2013). That shift was attributed to functional compensation for decrease in inhibitory control. However, the conjunction search task in that study had a strong working memory component, since the target stimulus varied on a trial-by-trial basis. As the types of search trials were intermixed, the parietal-to-prefrontal P300 shifts might be linked to the executive rather than to the orienting aspects of the search task.

5.6. *Healthy vs. normal aging*

The above findings raise the issue of whether impairments found in older populations are aging-inherent or effects of sub-clinical pathologies in neural integrity or transmission found in individuals within older adults samples. Indeed, complicating the investigation of attention, and indeed of any cognitive function in aging, is the fact that dementia processes and cerebrovascular disease may be present in an individual long before clinical symptoms are observed (Beason-Held et al., 2013; Lockhart and DeCarli, 2014). Studies with numbers of participants commonly employed in cognitive research are likely to include older participants in whom pathological processes may have already begun. Indeed, the prevalence of clinically silent cerebrovascular disease is so widespread as to recommend differentiating between normal aging, fundamentally including such deterioration, and healthy aging in its absence – the latter seemingly the exception rather than the rule (DeCarli et al., 2005). Epidemiologically, it makes sense to look at normal aging; cognitively, it is important to distinguish between inherent effects of healthy aging and those effects that, although common, are not necessarily present. Regarding the behavioral studies summarized above, as most comparisons of older with younger adults recruit older participants who are college educated and screened for acuity, health, and mental status, they may not necessarily represent even typical healthy aging, but instead may represent those older adults closer to the "optimal aging" end of the continuum. Moreover, the studies reported in this review are cross-sectional studies, comparing age-related differences between two or more groups at a certain time (Cavanaugh and Whitbourne, 1999). Given rapid changes in technology, social milieu, education, and even nutrition, one must be cautious about assuming that age-related differences merely represent the impact of aging processes, while they might represent cohort lifestyle effects.

Taken together, these reports of structural and functional changes in brain integrity in aging suggest that declines in attentional orienting are not unexpected, but that close attention should be paid to individual differences. Added research value may be gained by more carefully screening older participants in studies of orienting for signs of incipient degeneration or sub-optimal neuromodulation, as well as by performing longitudinal studies and including a varied sample of younger and older participants.

6. Discussion

In this paper, we have reviewed age-related effects on attentional orienting. The wide range of factors involved in this cognitive process, and the interactions between them, yield a complex and somewhat inconsistent pattern of aging effects, some of which are observed only under specific conditions. In the following sections, we will briefly summarize the findings of the above survey (see Fig. 3), integrating the behavioral and neural findings detailed above, and consider the implications of the pattern of results arising from the many studies that have touched on this topic.

6.1. *Overt vs. covert orienting*

While covert orienting is commonly found to be preserved across the life span under many conditions, older adults demonstrate a decline in overt orienting. As overt orienting involves head and eye movements, age differences in response times may be attributed to motoric changes as well as to attentional changes with age. Accordingly, as the attentional aspects of covert and overt orienting are considered to rely on the same mechanisms, it seems reasonable to recommend that further studies of aging influences on orienting should be tested by employing the covert shifting paradigm.

6.2. *Exogenous vs. endogenous orienting*

Studies using cueing paradigms commonly indicate that older adults shift their attention less rapidly or less effectively based on symbolic cues that direct attention to the probable location of target stimuli (endogenous orienting). In contrast, older adults generally exhibit no deficits in shifting attention in response to abrupt onset peripheral cues, even if those cues are probabilistically non-predictive (exogenous orienting). The apparent effects of older adults' greater exogenous orienting to non-predictive cues has been attributed to a decline in top–down processes responsible for inhibiting involuntary orienting. This interpretation is also offered to explain the decline in using some symbolic cues (eliciting endogenous orienting). However, some studies fail to find this age-related impairment. This inconsistency can be resolved by considering the type and complexity of the cues used in the paradigms (e.g., the unique effects of gaze cues), suggesting that age influences the ability to interpret cues, and not the spatial orienting process itself.

6.3. *Stimulus onset asynchrony*

SOA has been shown to mediate the impact of aging interactively with the type of orienting (endogenous vs. exogenous). For peripheral non-predictive cues, no age differences are found, even at very short SOAs. This finding is typically explained by the automatic processing of these cues. For symbolic cues considered to require more complex cognitive processing, age-related deficits are more often observed at short than at long SOAs. While these findings concord with the general slowing hypothesis of aging, they are not consistent (with several findings indicating an absence of aging effects in symbolic cueing paradigms).

6.4. *Post-orienting task factors*

Non-spatial characteristics also influence the impact of age on orienting. Interestingly, these include factors that come into play only after the orienting process has been completed, such as the type of task to be performed at the attended location. Orienting paradigms involving tasks of different levels of executive complexity yield different magnitudes of aging effects. As several studies indicate an executive decline in old age, it is possible that the tasks used in the orienting paradigm have different influences on different age groups. This type of interaction has been reported in practice only for endogenous orienting and long SOA.

6.5. *Benefits vs. costs*

In general, the interaction between orienting benefits, reorienting costs, and age is not well documented. As validity effects typically use an integrated measure based on RT differences between valid and invalid trials, most studies cannot rule out the possibility of different proportions of costs and benefits in older age. Since responding following an invalid trial involves additional neural networks than responding following a valid trial (i.e., ventral in addition to dorsal attention networks), it is possible that aging does not influence these processes to the same extent. It is therefore yet to be determined whether costs and benefits of valid and invalid cueing are equally influenced by aging. Findings of differential cortical degeneration affecting ventral parietal areas, and significant age-related volume losses in inferior parietal white matter point to the possibility of differential ventral network reorienting deficits in aging.

6.6. *Aging-stage effects*

Differences between early and later stages of old age have not been reported for detection tasks. For discrimination tasks, some differences have been found as a function of interactions between cue type and validity, cue-target overlap, and SOA, as well as later onset of IOR, seemingly indicating specific disengagement deficits.

6.7. *Object-based orienting*

The perceptual benefits of directing one's attention on the basis of coherent forms or objects in the visual space is a common finding in the orienting literature. Interestingly, although it has been established that older adults show deficits in perceptual organization, there is no indication of age effects on object-based orienting.

6.8. *Multi-feature visual search*

Orienting is considered to be involved in visual search. Age-related decline is rarely found in feature search, but is clearly evident in conjunction search, in the greater impact of age on performance as a function of the number of distractors. While larger search set size requires more orienting operations, it also requires more feature binding operations, more extensive marking of already tested items, and overcoming interference from more distractors. In some cases, age differences in basic processes may be ameliorated through functional compensation achieved by the recruitment of additional brain resources. Accordingly, the cause of the aging effects in visual search remains to be determined.

6.9. Temporal orienting

Temporal expectations influence the orienting process by directing attention to a point in time at which an event is expected in order to optimize responding. Interestingly, it seems that while younger adults can use temporal cues to enhance performance, older adults do not benefit from this predictive information. This is attributed to a general deficit in expectation mechanisms in old age, expressed as modulation of neural processing even in the absence of behavioral performance differences. This process may be linked to the age-related decline in noradrenergic neuromodulation. It should be noted that most studies using fixed SOAs inherently involve temporal cueing. Overlooking the expectations resulting from this type of cueing may explain some of the inconsistencies in the orienting literature.

6.10. Brain substrates of orienting

Aging has been found to involve structural changes in the volume and thickness of frontal and parietal cortical regions that support attentional orienting, as well as in white matter integrity important for functional connectivity between relevant regions. Furthermore, aging impacts adversely on cholinergic and noradrenergic neuromodulatory systems that have been implicated in orienting efficiency. The absence of pseudoneglect in older populations is taken as evidence for specific declines in right hemisphere function, with implications for orienting systems. However, given evidence of compensatory recruitment of neural resources by older adults, healthy aging may not involve obligatory decline in all aspects of orienting function. The issue of differences between age-related in orienting benefits vs. reorienting costs, that may map onto separable ventral and dorsal fronto-parietal networks, seems especially worthy of further behavioral and neural investigation.

7. Conclusions

Taken altogether, the findings just summarized present a complex picture of factors involved in the impact of aging on the orienting of attention. While there is ample evidence of age-related decline in orienting, careful examination of the relevant studies suggests that the interaction with other aspects of attention such as executive control, or mediating factors such as cue interpretation, feature binding, or general slowing, may have a profound impact on age-based deficits. Additional relevant factors, such as lateralization and separate examination of orienting benefits and reorienting costs, have rarely been assessed or controlled for, and must be considered as additional mechanisms mediating findings of previous studies. The complex picture emerging from this review implies that the relationship between aging and attentional orienting depends on the specific circumstances under which orienting is performed.

A parallel conclusion emerges from neural perspectives on aging. Although it is beyond the scope of the present review to fully survey the brain changes in aging relevant to the neuroanatomy and neurophysiology of orienting, the brief selection of findings to which we have alluded above suggests that there are likely to be great individual differences in the integrity of the brain substrates of orienting. It is possible that many older people who do not develop dementia processes or cerebrovascular disease – i.e., those who enjoy healthy aging – may not exhibit decline in orienting their attention.

Given the importance of orienting attention for the functions of everyday living noted above – pedestrian mobility, vehicle operation, effective use of complex computer interfaces, and safety from falls – going beyond the data currently available towards a clearer characterization of the circumstances under which orienting is spared or impaired over the lifespan is an important desideratum.

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