Predictivity and Manifestation Factors in Aging Effects on the Orienting of Spatial Attention

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Abstract

Objective

Prior attention research has asserted that endogenous orienting of spatial attention by willful focusing may be differently influenced by aging than exogenous orienting, the capture of attention by external cues. However, most such studies confound factors of manifestation (locational vs. symbolic cues) and the predictivity of cues. We therefore investigated whether age effects on orienting are mediated by those factors.

Method

We measured accuracy and response times of groups of younger and older adults in a discrimination task with flanker distracters, under three spatial cueing conditions: non-predictive locational cues, predictive symbolic cues, and a hybrid predictive locational condition.

Results

Age differences were found to be related to the factor of cue predictivity, but not to the factor of spatial manifestation. These differences were not modulated by flanker congruency.

Discussion

The results indicate that the orienting of spatial attention in healthy aging may be adversely affected by less effective perception or utilization of the predictive value of cues, but not by the requirement to voluntarily execute a shift of attention.

Keywords: attention, orienting, spatial, endogenous, exogenous

Introduction

Among the cognitive abilities subject to lifespan changes are those that comprise the realm of attention. Attention is not a unitary phenomenon, but rather reflects manifold interrelated processes, supported by multiple neural networks (Petersen & Posner, 2012). One of these processes is the orienting of attention, our ability to anticipate significant stimuli in their spatio-temporal context in order to process and/or respond to them more efficiently (Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014; Kingstone et al., 2002; Posner & Petersen, 1990). Exploring if and how such orienting processes may be affected by aging is important for understanding challenges older adults may have in everyday activities (Erel & Levy, 2016).

Of importance to appraising aging effects on orienting is the distinction between voluntary and involuntary focusing of attention (Jonides, 1981; Müller & Rabbitt, 1989; Posner, 1980). Often, attention can be fixed or shifted voluntarily, that is, according to one's own goals and expectations about where important stimuli may appear. This willful focusing is often called *endogenous* orienting of attention. Attention can also be involuntarily captured by external stimuli, whether they match one's goals or not. Such capture by external signals is often called *exogenous* orienting of attention. There is general consensus that exogenous and endogenous modes of deploying attention are subserved by mechanisms that are at least partly independent (e.g., Briand & Klein, 1987; Carrasco, 2011; Klein, 1994; Klein, Kingstone, & Pontefract, 1992; for review see Chica, Bartolomeo, & Lupiáñez, 2013).

In a recent literature survey, we have catalogued numerous studies addressing the influence of aging on endogenous and exogenous modes of orienting (Erel & Levy, 2016).

Older adults seem not to be impaired in shifting attention in response to peripheral cues that capture attention (i.e., exogenous orienting). For example, Lien, Gemperle and Ruthruff (2011) showed that behavioral measures and the N2pc ERP effect showed no age differences caused by the interaction between two overlapping non-predictive exogenous cues. They conclude that aging does not render one more susceptible to attentional capture by salient but task-irrelevant cues, at least regarding their modulation of exogenous non-predictive cueing. If anything, older adults might be more susceptible to exogenous cueing than younger adults (Brodeur & Enns, 1997; Faust & Balota, 1997). In contrast, the idea that older adults shift their attention less rapidly or less effectively in response to central symbolic predictive cues, i.e., endogenous orienting, has been the point of departure of many studies (e.g., Tellinghuisen, Zimba, & Robin, 1996). However, while there have been some reports of age-related decline in endogenous orienting (e.g., Brodeur & Enns, 1997; Folk & Hoyer, 1992, Exp. 2), the literature as a whole does not support this putative categorical dissociation. Many studies do not report decline in aging of top-down orienting processes (see discussion in Maylor et al., 2011), or have found indications that observed differences might be attributed to general slowing in aging (Folk & Hoyer, 1992; Lincourt et al., 1997).

The notion that endogenous orienting should be more vulnerable to aging effects than exogenous orienting seems to be based on the fundamental assumption that top-down executive processes are especially affected in old age, which is almost a canonical principle of aging research (Lustig & Jantz, 2015; but see Verhaeghen, 2011). Why, then, are aging effects on endogenous attention so rarely observed?

One reason might be that traditionally, endogenous cueing paradigms utilized arrow symbols that pointed to the target's location. Such cues can lead to attentional shifts even if they are not informative (e.g., Friesen & Kingstone, 1998; Friesen et al., 2004; Langley et al., 2011; Ristic et al., 2007). Seemingly, some common symbols entrain spatial information automatically, thereby circumventing volitional control of attention. Thus, effective investigation of endogenous attention should employ symbolic cues that are associated with specific locations only in the instruction stage of the experiment (e.g., Olk & Kingstone, 2015). As described below, we accomplish this using auditory verbal symbolic cues, which require central processing and cross-modal transfer of cue information to be applied in the visuo-spatial realm.

Furthermore, a fuller understanding of the relationship between exogenous and endogenous processes in attention requires avoiding the confounding of two factors that are commonly manipulated in this research. In many of the above-cited studies, modes of attentional focusing have been studied using variations of the cueing paradigm (Müller & Rabbitt, 1989; Posner, 1980). In this paradigm, participants are asked to search for a target that appears in one of several potential locations. A cue appears immediately prior to the target, indicating either the target's location (valid cue) or an alternative location (invalid cue). Greater accuracy, and especially faster reaction times, are expected in the valid cue condition than the invalid cue condition (henceforth: *validity effects*). In order to differentiate between endogenous and exogenous focusing of attention, researchers often use cues that differ in two properties: *manifestation* (locational vs. symbolic) and *predictivity*. Manifestation refers to the manner in which the cue indicates a location. Locational cues are simple stimuli (e.g., a flash of color) that appear in one of the locations potentially occupied by the subsequent target. In contrast, symbolic cues never overlap with the target's location, but their interpretation denotes a specific location. Predictivity refers to the degree to which the cue reliably informs the participant about the target's actual upcoming location. Both cue dimensions are crucial in order to isolate voluntary and involuntary attention in the cueing paradigm. Exogenous cueing paradigms use *non-predictive locational* cues. Locational cues produce an external signal that rapidly captures attention to its location due to its salience. However, in this paradigm the location of the cue is random, and therefore attending to the cue carries no strategic benefit to the participant. Thus, validity effects following non-predictive locational cues can only be attributed to exogenous capture of attention. In contrast, endogenous attention is recruited by using *predictive symbolic* cues. Since the cue is predictive, participants are encouraged to use the cue to their advantage and allocate attention towards it. As the cue is symbolic, it can lead to an attentional shift only if its meaning is correctly interpreted and volitionally acted upon.

As noted above, many studies using these paradigms have revealed no age differences in validity effects following non-predictive external cues, but some have found differences following symbolic predictive cues. However, age-related differences in the endogenous cueing paradigm can be attributed to one of two factors (Brodeur & Enns, 1997). It may be that older adults are less efficient in utilizing information from the environment that can improve their performance. If the importance (i.e., the predictive value) of the symbolic cue is neglected, it will not motivate a proactive attentional shift. Alternatively, older adults may have a reduced capacity to voluntarily shift their focus of attention efficiently. In other words, it is possible that the execution of the planned shift, rather than the planning itself, is compromised in older adults. A similar distinction has been made in regards to executive dysfunction in older adults (Allain et al., 2005).

The current study

In order to adjudicate these two possibilities, a test paradigm yielding differential predictions is required. Importantly, we note that each possibility relates to a different aspect of the cue: while differences in planning rely on participants noticing the cue's predictivity (regardless of whether this cue is symbolic or locational), differences in execution are a function of the cue's manifestation, that is, whether the signal to shift attention is generated internally (following a symbolic cue) or entrained by an external source (following a locational cue). The ambiguity between the two aforementioned possibilities cannot be resolved by comparing predictive symbolic cues to non-predictive locational cues. Therefore, we also examine age-related differences in responding to a hybrid *predictive locational* condition, in which a cue appearing in a particular location predicts the place of the target's appearance with high validity. The two explanations of aging effects on endogenous orienting yield different predictions regarding validity effects in this condition as compared with the exogenous non-predictive and endogenous predictive conditions.

The first comparison of interest regards the non-predictive and predictive locational cues. These two conditions are identical except for the cue's informativeness. We expected young adults to show a larger orienting benefit following a predictive locational cue, which would indicate that they utilized the cue's predictive value. If older adults are indeed less efficient in processing predictivity, they would be less able to utilize the predictive locational cues to their benefit, and should therefore show a smaller difference in orienting benefit between the two conditions. The second comparison of interest is between the predictive locational and symbolic cues. Given that the locational predictive cue circumvents the need to volitionally orient attention, we expected younger adults to show a larger location orienting benefit in this condition relative to the symbolic predictive cue. If older adults are indeed less efficient in executing the orienting of attention, they should exhibit an even larger difference between the two predictive conditions than young adults.

Note that these predictions are not mutually exclusive, as it is possible that both mechanisms are disrupted in older adults. Moreover, it should be emphasized that these predictions do not pertain to age differences in each cue condition, but mainly to the validity effects of the hybrid predictive locational condition cues relative to the other two conditions. However, in accordance with previous studies (see Erel & Levy, 2016), we also expected that older adults would show an equal or larger cueing benefit than young adults following the non-predictive locational cue.

Two previous studies have examined age-related differences using this hybrid predictive locational condition. In the study of Juola, Koshino, Warner, McMickell and Peterson (2000), each trial of a target detection task began with the presentation of a predictive symbolic cue, which was followed by a second locational cue. Importantly, the locational cue could be either predictive or non-predictive of the target's location. Juola and colleagues found that both young and old adults were equally likely to reorient towards the predictive locational cue, but older adults were more likely to reorient towards the non-predictive locational cue. Note that in Juola et al. (2000), unlike the standard cueing paradigm, it was counterproductive to reorient attention towards a non-predictive cue, since attention had already been oriented towards the location of the symbolic predictive cue. Thus, the results show that older adults are less likely to inhibit a shift towards an exogenous cue when that cue is detrimental to the task at hand. Indirectly, this finding suggests that while younger adults attended to the locational cues selectively, based on their predictivity, older adults did not differentiate between the two.

Olk and Kingstone (2015) examined age-related differences in a study that manipulated both the cue's predictivity and its manifestation. As expected, for both age groups, non-predictive locational cues captured attention, whereas non-predictive symbolic cues did not. Importantly for the present question, when predictive cue conditions were compared, both age groups were equally more likely to orient towards the locational cues than towards the symbolic cues. If the ability to execute a volitional shift was disrupted with age, one would have expected older adults to benefit less from valid symbolic cues. This finding may be thus be seen as indicating that the volitional shifting of attention is preserved in aging. However, unlike several previous studies listed above, Olk and Kingstone (2015) did not find age-related differences in their predictive locational cue condition (at least at short and intermediate SOAs of 100 and 450 ms), nor in their symbolic cue condition. Consequently, the question remains whether older adults would benefit from cueing in the hybrid predictive locational condition under conditions in which they show less effective responding to predictive symbolic cues, as is sometimes the case.

We therefore conducted an extended replication of the multi-condition orienting study. Along with conditions of non-predictive locational cues and hybrid predictive locational cues, we employed auditory verbal signals as symbolic cues for endogenous orienting. In principle, symbolic non-predictive cues are also factorially possible, but as might be expected given their null informativeness and non-appearance in the monitored space, these are quite ineffective in orienting attention (Olk & Kingstone, 2015), so we did not include that type of cueing in this study.

We conducted the relevant comparisons in a version of Posner's ANT (attentional networks test) paradigm, often employed for testing aging differences in the orienting of attention (e.g. Gamboz et al., 2010; Jennings et al., 2007). This requires target discriminating in the presence of potentially incongruent distractors, such that executive function demands could be present or absent. Furthermore, the possible spatial locations of target appearance were distributed vertically (above and below fixation), which circumvents confounds conceivably arising from possible age-related impairments in responses to targets in the left visual field, following decline in inferior parietal lobe-based ventral attention network function (Karnath, 2015). Using this paradigm, differential performance across conditions of predictivity and manifestation would enable resolution of the question whether aging might involve decline in the planning or execution aspects of orienting.

Method

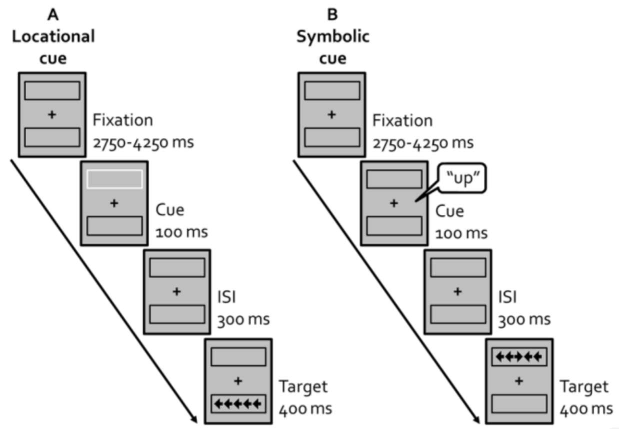

Figure 1. A schematic diagram of the Attention Networks Test (ANT) paradigm with locational cues (A) and symbolic cues (B). In valid trials, the target appears in the cued location; in invalid trials, in the alternative location. In predictive versions, the cue predicts the location of the target in 75% of the trials; in the non-predictive version, the cue predicts the location of the target in 50% of the spatial cues. In all versions, there are also double cue (providing temporal but not spatial cueing) and no-cue conditions. The example on the left corresponds to the invalid cue, congruent flankers condition. The example on the right corresponds to the valid cue, incongruent flankers condition.

Attention Networks Test (ANT)

The ANT paradigm enables simultaneous testing of the putative alerting, executive control, and orienting components of attention, as well as the interactions between them (Fan et al., 2002, 2009; Posner & Rothbart, 2007). ANT combines the Posner spatial cueing task (Posner, 1980) and the Eriksen flanker task (Eriksen & Eriksen, 1974). Our version of this paradigm used the following characteristics. At the beginning of each trial, a fixation point appeared for a randomly variable duration. In most trials the fixation was followed by a cue, and after a further delay, the target was displayed above or below the fixation point (see Figure 1). Participants were asked to indicate by keypress whether a target arrow was pointing right or left. The target arrow was flanked either by arrows pointing in the same direction (congruent) or in the opposite direction (incongruent). Three types of cues could precede the target stimulus with a constant SOA of 400 ms. *Double* cues (signaling both possible spatial locations) are temporal cues, offering no spatial information. *Valid* and *Invalid* cues provide both temporal and spatial (location) information. The valid cue correctly indicated the following target location; the invalid cue indicated the opposite location. In a fourth *(No cue)* condition, no cue preceded the target.

Cue distribution within a session could differ in *predictivity*. A predictive distribution involved Valid (144 trials), Invalid (48 trials), Double (48 trials), and No cue (48 trials) bins, yielding a 75% valid vs. 25% invalid spatial cue ratio. A non-predictive distribution involved Valid (96 trials), Invalid (96 trials), Double (48 trials), No cue (48 trials), yielding a 50% valid vs. 50% invalid spatial cue ratio. These cue distributions enable testing different aspects of attentional functions as defined in Posner's model (Posner & Peterson, 2012). Orienting is assessed by the RT and accuracy differences between the invalid and valid cue conditions. Executive control is assessed by the RT and accuracy differences between the congruent and incongruent trials, averaged across all cueing conditions (Fan et al., 2009). Alerting is generally assessed by the RT and accuracy differences between the no-cue condition and the double-cue condition; we will not analyze this this aspect of attention, as it is beyond the purview of the present study. However, we provide the data for these conditions in the supplementary data (Supplementary Table 1).

The cues used in our paradigm could also differ in *manifestation,* triggering either exogenous or endogenous orienting of attention. Exogenous attention was recruited by a locational cue – a box flashing at one of the two possible target locations (above or beneath fixation). Endogenous attention was recruited by symbolic auditory cues, specifically, the words "up" or "down" indicating one of the two possible target locations. This type of cue requires semantic processing of the meaning of the cue word and transduction of that information into a spatial parameter, followed by a volitional shift of attention to that location. In this study, three ANT versions were employed: non-predictive locational cueing (purely exogenous); predictive locational cueing (hybrid exogenous-endogenous); and predictive symbolic cueing (purely endogenous), in a between-subjects paradigm instantiating the abovementioned factors of predictivity and manifestation. We chose to administer the versions to different participants, as older adults were generally unwilling to take part in more than one session of this type of testing. We therefore prioritized having enough trials in each condition of the experiment.

ANT Version 1 (Non-predictive locational cues)

Participants

43 older adults (14 males and 29 females; mean age: 70.6, SD = 5.3) and 45 young adults (17 males and 28 females; mean age: 22.0, SD = 3.1) participated in the study. The older adults were self-reportedly healthy community-dwelling volunteers. They were compensated for travel expenses and received a coffee shop voucher for their participation. A Snellen test of visual acuity was conducted for each older participant, who used corrective eyewear if necessary. Audiological testing indicated that all older participants

had pure-tone air-conduction thresholds within clinically normal limits. Younger adults were psychology undergraduates at the Interdisciplinary Center Herzliya, who received course credit for participation. All participants provided informed consent for a protocol approved by the human subjects research ethics committee of the Interdisciplinary Center Herzliya.

Procedure

Each trial consisted of the following sequence of events: a black fixation cross was presented in the middle of a gray screen, along with two black rectangles. The rectangles were 3-pixels thick, 13.7° X 2.7° in size, and appeared 4° (center-to-center) above and below the fixation point. Fixation duration randomly varied between 2250 ms to 4750 ms, in increments of 250 ms. After that, a cue display appeared for 100 ms, randomly containing one of the four possible cue types (Valid [96 trials], Invalid [96 trials], Double [48 trials], No-cue [48 trials]). Cueing was accomplished by having one rectangle briefly changing its color to white. In the Valid cue condition, the target appeared in that rectangle, and in the Invalid cue condition it appeared in the alternative location. In the Double cue condition, both rectangles changed their color to white before the target appeared in one of them. In the No-cue condition, none of the rectangles changed their color.

The cueing display was followed by an additional fixation display of 400 ms, after which the target appeared on the screen for 500 ms, to which participants could respond for up to 1400 ms. The target consisted of a string of five 1.6° X 1.1° arrows, 1 mm apart, that appeared in one of the two rectangles. Participants were required to identify the direction of the central target arrow by pressing the left-sided ("A") key on the keyboard, using the left index finger, or pressing the right-sided ("L") key on the keyboard, using the right index finger. The experiment began with six practice trials. Participants than performed four blocks of 72 trials with short breaks between them. Flanker congruency and cue type combinations were balanced evenly within each block.

ANT Version 2 (Predictive locational cueing)

Participants

43 older adults (19 males and 24 females; mean age: 72.9, SD = 6.2) and 44 young adults (19 males and 25 females; mean age: 22.7, SD = 4.1) participated in this version. All other details were the same as for Version 1.

Procedure

The procedure was similar to Version 1 except for the distribution of the cues: 144 valid, 48 invalid, 48 double, and 48 no-cue, yielding a 75% valid to 25% invalid spatial cue ratio.

ANT Version 3 (Predictive symbolic cueing)

Participants

39 older adults (11 males and 28 females; mean age: 72.1, SD = 5.9) and 46 young adults (21 males and 25 females; mean age: 24.1, SD = 4.3) participated in the study. All other details were the same as for Versions 1 and 2.

Procedure

The procedure was similar to Version 2 except for the cue types. In this version, auditory word cues were employed to trigger endogenous attention. For the valid cues (144 trials) the word “up” or “down” indicated that the following target location would be either above or beneath fixation. In the invalid cues (48 trials), the target appeared in the opposite location to the one predicted by the auditory word cue. In the double cues (48 trials), both words (“up” & “down”) were played at the same time before the target appeared on the screen. In the no-cue trials (48 trials), participants did not receive any auditory cue.

Statistical analysis

As often noted in studies of aging, older adults show a general slowing of reaction times (RT). This is problematic for research of age differences in general, and research of age differences in attentional orienting in particular, as longer reaction times often result in artificially inflated differences between conditions (Faust, Balota, Spieler, & Ferraro, 1999). Thus, even if older adults had no deficit in attention, one would expect validity effects in raw RTs to be larger for older adults, seeing as their overall RTs are slower. To resolve this issue, we transformed our RT data using a z-transformation, in which a participant’s RT in a specific condition is expressed as the standard deviation from the overall RT (i.e., the difference between an RT in a specific condition and the participant’s average RT, divided by the participant’s standard deviation). This method was recommended by Faust et al. (1999), and is commonly used in the study of age differences in attention (e.g., Olk & Kingstone, 2015; Williams et al., 2016). We also note that while there is no agreement regarding which transformation method provides the best correction to general slowing, all the results reported below were fully replicated when we applied a proportional transformation, in which validity effects are calculated as the proportion between invalid cue RTs and valid cue RTs (e.g., in Pratt & Bellomo, 1999; Lincourt, Folk & Hoyer, 1997), as well as when we analyzed log-transformed RTs, suggesting that the conclusions are not dependent on a particular method of analysis (see Supplementary

Materials). Finally, though we consider examination of untransformed RTs not to be the optimal approach to characterizing age effects, we report these data alongside Z-transformed RTs and accuracy rates as a function of the different experimental conditions in Table 1, and provide a detailed analysis of raw RTs in the Supplementary Material.

Results

Participants were removed from the final sample if their accuracy was lower by more than 3 standard deviation from the average accuracy (i.e., less than 64.4% accuracy). This led to the rejection of 5 young adult and 5 older adult participants. RT analysis was conducted on accurate trials only. Trials with an RT deviating from the mean RT of each subject and each cell by more than 3 absolute deviations (1.1% of correct trials) were excluded from further analysis.

As a preliminary analysis, we entered z-transformed RTs and error rates as dependent variables in an ANOVA with the factors of age group (young adult vs. old adult; between-subjects), cue format (locational non-predictive, locational predictive and symbolic predictive; between-subjects), cue validity (valid vs. invalid; within-subjects) and distractor congruency (congruent vs. incongruent; within-subjects) as independent variables. The results of these analyses are presented in Table 2.

Table 1. Mean RTs in ms, Z-transformed RTs, and accuracy rates, as a function of age group, cue format, cue validity and congruency.

Cue format	Congruency	Validity	Young adults			Older adults		
			RT	Z_{RT}	% correct	RT	Z_{RT}	% correct
Non-predictive locational	Congruent	Valid	492	-0.83	0.98	648	-0.95	0.97
		Invalid	609	0.04	0.98	815	0.11	0.96
	Incongruent	Valid	639	0.21	0.87	795	-0.03	0.95
		Invalid	728	0.91	0.83	944	0.9	0.93
Predictive locational	Congruent	Valid	462	-0.64	0.98	702	-0.62	0.97
		Invalid	597	0.38	0.97	876	0.41	0.96
	Incongruent	Valid	574	0.16	0.83	842	0.15	0.88
		Invalid	753	1.54	0.76	1030	1.29	0.80
Predictive symbolic	Congruent	Valid	509	-0.58	0.99	660	-0.57	0.98
		Invalid	582	-0.02	0.97	730	-0.14	0.98
	Incongruent	Valid	641	0.31	0.91	817	0.36	0.94
		Invalid	748	1.13	0.82	907	0.93	0.89

Table 2. Results of four-way ANOVA on Z-transformed RTs and accuracy with age group, cue format, cue validity and congruency as independent variables.

Effect	**Z_{RT}**	**Accuracy (%)**
Main effects		
Age group (A)	$F(1,222) = 11.65, p < .001$	$F(1,222) = 3.0, p = .085$
Cue format (F)	$F(1,222) = 87.52, p < .001$	$F(2,222) = 3.7, p = .025$
Cue validity (V)	$F(1,222) = 1252.80, p < .001$	$F(1,222) = 60.7, p < .001$
Congruency (C)	$F(1,222) = 2225.87, p < .001$	$F(1,222) = 121.7, p < .001$
Two-way interactions		
A X F	$F(1,222) = 0.15, p = .86$	$F(2,222) = 0.3, p = .70$
A X V	$F(1,222) = 0.39, p = .53$	$F(1,222) = 3.8, p = .051$
A X C	$F(1,222) = 5.24, p = .023$	$F(1,222) = 10.3, p = .002$
F X V	$F(1,222) = 42.03, p < .001$	$F(2,222) = 5.3, p = .005$
F X C	$F(1,222) = 3.13, p = .046$	$F(2,222) = 3.9, p = .02$
V X C	$F(1,222) = 12.12, p < .001$	$F(1,222) = 64.9, p < .001$
Three-way interactions		
A X F X V	$F(1,222) = 5.96, p = .003$	$F(2,222) = 0.2, p = .81$
A X F X C	$F(1,222) = 1.06, p = .35$	$F(2,222) = 0.9, p = .42$
A X V X C	$F(1,222) = 3.51, p = .062$	$F(1,222) = 5.3, p = .02$
F X V X C	$F(1,222) = 19.01, p < .001$	$F(2,222) = 14.9, p < .001$
Four-way interaction		
A X F X V X C	$F(1,222) = 2.44, p = .089$	$F(2,222) = 0.5, p = .58$

We remind the reader that our main goal was to examine age-related differences in orienting, as mediated by the factors of predictivity (predictive vs. non-predictive) and manifestation (locational vs. symbolic). As can be seen from Table 2, the effect of congruency interacted with cue validity, but the three-way interactions and the four-way interaction that included age and this factor did not reach statistical significance. Therefore, we did not further examine the effect of congruency.

Of main importance was the significant three-way interaction between age, cue format and cue validity on RTs. This effect suggests that orienting in response to valid cues was modulated by both age and cue format. We therefore proceeded to investigate this interaction by conducting two further analyses enabling the examination of the factors of predictivity and manifestation. First, to focus on the measure of interest, we calculated the mean validity effects for z-transformed RTs (i.e., expressing the validity effect in standard deviations) and error rates for each participant. Then, we entered these validity effects as dependent variables in two analyses: (1) to examine the effect of predictivity, we compared performance after non-predictive locational cues vs. predictive locational cues; (2) to examine the effect of manifestation, we compared performance after predictive locational cues vs. predictive symbolic cues. Mean validity effects are presented in Figure 2.

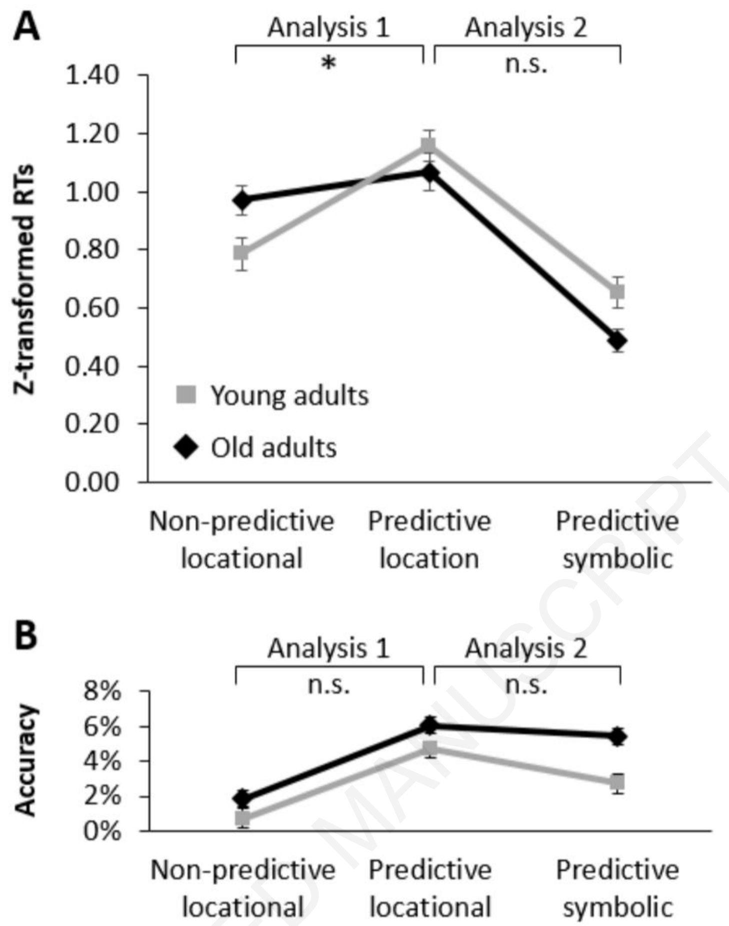

Figure 2. Validity effects, calculated as the difference between (A) Z-transformed RTs and (B) accuracy rates on valid vs invalid trials, as a function of age-group and cue format. Analysis 1 examined the effect of predictivity while controlling for cue manifestation and Analysis 2 examined the effect of manifestation while controlling for cue predictivity. Error bars represent standard error of the mean.

Analysis 1: Age and predictivity modulation of validity effects

For this analysis we excluded the predictive symbolic cue condition. Cue validity effects were entered as a dependent measure in an ANOVA with age group (young vs. old) and cue predictivity (predictive vs. non-predictive) as between-subjects independent variables.

z-transformed RTs. The ANOVA revealed a main effect of cue predictivity, F(1,150) = 15.64, p < .001, η_p^2 = .09, as well as an interaction between age group and cue predictivity, F(1,150) = 5.28, p = .023, η_p^2 = .03. Follow-up analysis indicated that the validity effect was larger when the cue was predictive than when it was non-predictive for young adults, F(1,150) = 22.67, p < .001, η_p^2 = .13, but not for old adults, F(1,150) = 1.21, p = .27, η_p^2 = .01. The main effect of age was not significant, F < 1.

Accuracy. Validity effects in error rates were larger following the predictive locational cue than non-predictive locational cue, F(1,150) = 22.46, p < .001, η_p^2 = .13. None of the other effects were significant, both ps > .15.

Analysis 2: Age and manifestation modulation of validity effects

For this analysis we excluded the non-predictive locational cue condition. Cue validity effects were entered as a dependent measure in an ANOVA with age group (young vs. old) and cue manifestation (locational vs. symbolic) as independent variables.

z-transformed RTs. The ANOVA revealed a main effects of age, F(1,154) = 5.11, p = .025, η_p^2 = .03, and of cue manifestation, F(1,154) = 93.145, p < .001, η_p^2 = .38. The cue validity effect was larger for younger adults than for older adults and following a locational cue than following a symbolic cue. However, the superiority of locational cues over symbolic cues was not modulated by the age-group as indicated by the absence of a two-way interaction between the two factors, $F < 1$.

Accuracy. None of the effects were significant, all ps > .11.

Discussion

The aim of the current study was to examine age-related differences in the endogenous orienting of attention, and whether such differences might be caused by changes in older adults' ability to plan an attentional shift, or by changes in their ability to execute it. We found age differences in endogenous orienting following verbal symbolic cues, which arguably require a strong degree of endogenous processing to shift attention. We also examined age-related differences in orienting following hybrid predictive locational cues, which combines both exogenous and endogenous aspects: it provide an external signal to which participants should want to attend, assuming that they perceive its predictive value, but at the same time circumvents the need to volitionally execute the shift of attention. The validity effect in this cue condition was equally larger for both age groups than the validity effect in the purely endogenous (and predictive) cue condition. This result suggests that older adults are equally efficient in producing the internal signal responsible for the execution of the volitional attentional shift. Otherwise, older adults should have benefitted more from an external guiding signal than the young adults. In contrast, when comparing between the non-predictive and predictive locational cues, young adults showed a clear preference to orient towards the predictive cue, while older adults showed a non-significant difference between the two conditions. This finding suggests that older adults are less efficient in utilizing predictive information that can improve their performance. We conclude that age-related differences in endogenous orienting of attention are due to older adults' failure in planning an attentional shift, not due to a deficit in executing it. Thus, our findings offer a more complex and nuanced picture of aging effects on orienting than prior studies, and indicate that the factors of cue predictivity and manifestation may be key elements in aging effects on attention.

We also note that older adults showed a larger orienting benefit than younger adults the non-predictive condition, $F(1,150) = 4.26$, $p = .041$, $\eta_p^2 = .03$. This finding can be taken as further support for our conclusion that older adults neglect predictive information, for they are less likely to suppress the irrelevant and generally unhelpful signal. However, we hesitate to base any strong conclusions on this finding for two reasons. First, unlike the other analyses, this finding does not replicate when a different transformation was used (see Supplementary Figure 1B), making the finding more tenuous. Second, this finding is not compatible with many previous studies which found no difference in exogenous orienting between young and old adults (e.g., Lien et al., 2016; Lincourt et al., 1997; Pratt & Bellomo, 1999; Williams et al., 2016, but see: Brodeur & Enns, 1997; Faust & Balota, 1997).

In our survey of age-related changes in orienting (Erel & Levy, 2016), we reviewed the literature documenting the interaction of stimulus onset asynchrony (SOA) on RTs in younger and older adults. At very short cue-target intervals (100 ms and less), older adults might be hard-pressed to engage in cue processing due to general slowing. On the other side of the spectrum, in long intervals (850 ms and above), exogenous and endogenous cue conditions are expected to yield opposite effects due to the inhibition of return (IOR) found to occur at longer latencies in exogenous cueing paradigms (Chica, Lupiáñez, &

Bartolomeo, 2006, and sources cited by Erel & Levy, 2016). To avoid these complications masking the factors of interest in this study, and to measure a large number of data points for each participant in each condition of interest, we only employed a 400 ms SOA in all conditions. This indeed appears to have enabled older adults to engage in cue processing before target appearance, across conditions, as borne out by the non-zero orienting benefits in older adults in all conditions.

Several limitations of this study are worth noting. Of main importance is the disparity between age-related patterns in validity effects on raw (untransformed) RT and z-transformed RT data (see Table 1). Such disparities are to be expected in studies of age-differences on RTs, given that older adults are generally slower than younger adults (Faust et al., 1999). Indeed, normalizing RT data can often reverse previously held conclusions about age differences (e.g., Lincourt et al., 1997), making progress in the study of age difference arduous. However, we feel that our interpretation of the findings is the appropriate one for two main reasons. First, our z-transformed analysis converges with results from both proportional and log transformations. Second, the conclusions that can be drawn using raw RTs are implausible from a theoretical standpoint (see supplementary material for a detailed analysis and discussion). Another limitation of this study is that we did not monitor eye movements, which means that attentional shifts may have been overt and not covert. As it stands, this possibility is not problematic to our conclusion, as the only deficit in older adults' attention was found to be related to the pre-execution stage.

There are several aspects of attention that can be assessed using the ANT that we did not analyze or elaborate on. First, congruency effects are often used as measures of attention filtering or executive control, and can therefore contribute to the literature on age differences in those abilities (e.g., our results replicate D'Aloisio & Klein, 1990, who found that older adults have larger filtering costs in raw RTs but smaller costs in accuracy rates). Since we found no interaction between congruency and age effects on orienting, we did not examine that issue further. Second, the RT and accuracy differences between the no-cue condition and the double-cue condition are used to measure the alerting aspect of attention; again, this is beyond the purview of the current study (the data from these conditions is presented in the Supplementary Materials). Third, the validity effect can be broken down to two components: the benefit associated with orienting attention to the correct location and the cost associated with the need to disengage from the non-target location. These factors deserve extensive exploration in their own right and will be discussed elsewhere (Zivony, Erel & Levy, in preparation).

It is notable that deficits in utilizing cue predictivity by older adults has also been observed in attentional orienting in the temporal domain. Targets appearing at a predicted time interval following a non-spatial cue are detected more efficiently (Coull & Nobre, 1998; Miniussi et al., 1999; Lange & Röder, 2006). However, older adults are less efficient in using such temporal contingencies (Bollinger et al., 2011; Zanto et al., 2011). Taken together, the evidence from the spatial and temporal domains might be suggestive of aging-related changes in anticipatory allocation of processing resources in response to cue contingencies. However, it is unclear whether these changes reflect a deficit in older adult's ability to engage expectation mechanisms by flexible cognitive control (as suggested by Bollinger et al., 2011; Zanto et al., 2011), or from deficient learning about cue contingencies (Saban, Klein, & Gabay, 2018). We intend to explore this issue in a future study.

A synoptic view of the results enables us to ask a slightly more comprehensive question: is the overall picture of aging effects on orienting of spatial attention optimistic or pessimistic? On one hand, we have determined that older adults are less able than younger adults to take advantage of predictive spatial cues, both exogenous and endogenous. On the other hand, examination of overall cue validity benefits to RTs and accuracy across congruency conditions and cue formats yields an additional perspective. While lower than the benefit derived by younger adults (14.1% of raw RT measures), older adults exhibited a 10.1% more rapid response following valid vs. invalid cues in the predictive symbolic condition. Similarly, older adults benefitted notably from predictive locational cues, exhibiting responses 22.3% faster following valid vs. invalid cues (with younger adults responding 26.9% faster). In the case of non-predictive locational cues, older adults' benefit from cue validity was even higher than that of younger adults (19.0% vs. 17.2%). So, is the glass of orienting in aging half-full or half-empty? It remains to be determined whether the aging-related changes identified in these laboratory tasks cause meaningful performance decrements in attentional function under ecological conditions of driving, pedestrian behavior, locating target information in a complex real-world screen display and other search functions vital for daily living.

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Supplementary Materials

1. Results from additional conditions in the ANT paradigm

The ANT paradigm includes two cue conditions that were outside the scope of the current study: namely, a double cue condition where both potential target locations were cued (see Methods) and an absent cue condition where none of the target locations were cued. These conditions do not pertain to orienting per se, but can be used to analyze alerting effects. For sake of completeness, we report the data from the conditions in Supplementary Table 1. We analyze and report conclusions that can be drawn from these conditions elsewhere (Zivony, Erel & Levy, in preparation).

Supplementary Table 1. Mean RTs in ms, Z-transformed RTs, and accuracy rates, as a function of age group, cue format and congruency, in the double cue and absent cue conditions, which were not analyzed in this study.

Cue format	Congruency	Validity	Young adults			Older adults		
			RT	Z_{RT}	% correct	RT	Z_{RT}	% correct
Non-predictive locational	Congruent	Double	550	-0.65	0.97	730	-0.64	0.96
		Absent	614	-0.15	0.99	798	-0.22	0.98
	Incongruent	Double	681	-0.04	0.82	885	0.33	0.94
		Absent	748	0.43	0.87	919	0.55	0.93
Predictive locational	Congruent	Double	524	-0.64	0.97	780	-0.55	0.96
		Absent	576	-0.22	0.98	834	-0.22	0.97
	Incongruent	Double	640	0.25	0.81	926	0.29	0.87
		Absent	707	0.79	0.87	971	0.60	0.89
Predictive symbolic	Congruent	Double	555	-0.64	0.96	704	-0.63	0.96
		Absent	621	-0.15	0.99	795	-0.05	0.98
	Incongruent	Double	682	0.16	0.82	825	0.08	0.93
		Absent	766	0.70	0.91	914	0.65	0.94

2. Additional analyses of reaction times

Older adults show a general slowing in reaction times relative to young adults. This is problematic for research of age differences in general, and research of age differences in attentional orienting in particular, as longer reaction times often result with artificially inflated differences between conditions (Faust, Balota, Spieler, & Ferraro, 1999). To illustrate this, we consider the following example: a drug company invents a performance-enhancing drug, which it claims will improve running performance for both short-distance and long-distance runners. The drug is given to amateur 100m sprint runners and amateur marathon runners. Before taking the drugs, the two groups score an average of 15 seconds and 4 hours, respectively. After taking the drug, both groups improve their score by an average of 5 seconds. Is the drug equally effective for both groups? In this example it is clear that a 5 second improvement in a sprint is very meaningful, while a 5 second improvement in a marathon is negligible. Similarly, when analyzing orienting effects, one should take into account differences in baseline performance, which in our study was approximately 600ms and 800ms for young adults and old adults respectively.

Several methods have been developed in order to control for older adults' general slowing (Brinley, 1965; Faust et al., 1999; Madden, Pierce, & Allen, 1992). The absence of a single agreed-upon method of analysis can hinder scientific progress because different methods can often lead to different conclusions. We used the z-transformed analysis which is recommended by Faust et al. (1999) and common in the study of age-differences in attention (e.g., Olk and Kingstone, 2015; Williams et al., 2016). In the section below, we re-analyze validity effects from our data using two additional methods:

(1) untransformed validity effects, where validity effects are expressed as the difference between invalid RTs and valid RTs (Supplementary Figure 1A); (2) calculating proportional validity effects, another common method used to control for differences in the baseline RTs (e.g., Lincourt, Folk & Hoyer, 1997; Pratt & Bellomo, 1999) in which validity effects are calculated as the ratio between invalid RTs and valid RTs (Supplementary Figure 1B).

Analysis 1: Age and predictivity modulation of validity effects.

For this analysis we excluded the predictive symbolic cue condition. Cue validity effects were entered as a dependent measure in an ANOVA with age group (young vs. old) and cue predictivity (predictive vs. non-predictive) as between-subjects independent variables.

Untransformed RTs validity effect. The ANOVA revealed a main effect of age, F(1,150) = 21.61, p < .001, η_p^2 = .13, as well as a main effect of cue predictivity, F(1,150) = 20.614, p < .001, η_p^2 = .12. The cue validity effect was larger for older adults than for younger adults and following a predictive cue than following a non-predictive cue. The interaction between the two factors was not significant, F(1,150) = 1.84, p = .18, η_p^2 = .01.

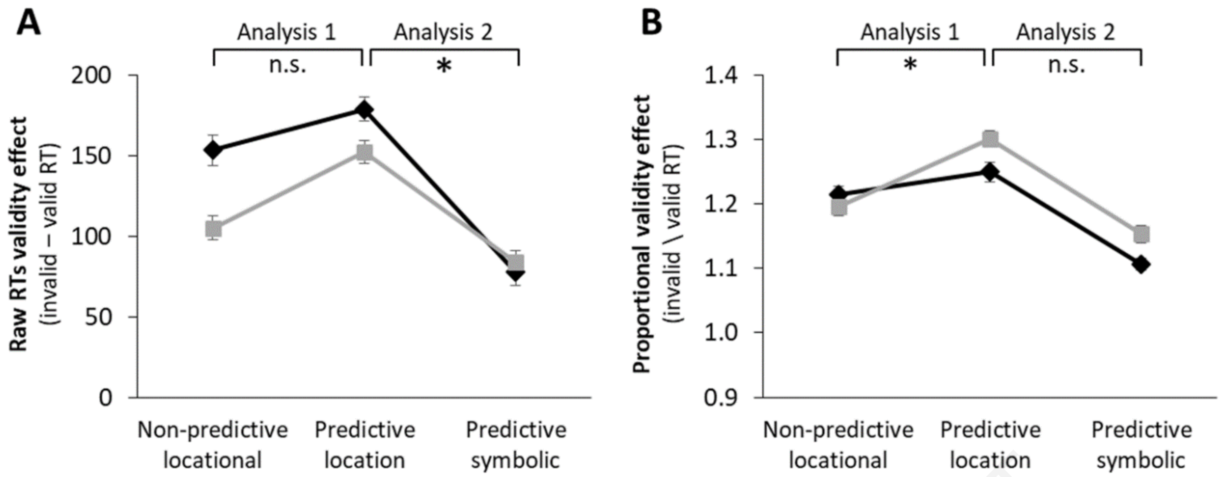
Proportional validity effect. This analysis replicated the results reported with the z-transformed RTs. The ANOVA revealed a main effect of cue predictivity, F(1,150) = 22.27, p < .001, η_p^2 = .13, as well as an interaction between age group and cue predictivity, F(1,150) = 5.71, p = .018, η_p^2 = .04. Follow-up analysis indicated that the validity effect was larger when the cue was predictive than when it was non-predictive for young adults, $F(1,150) = 29.32$, $p < .001$, $\eta_p^2 = .13$, but not for old adults, $F(1,150) = 2.38$, $p = .13$, $\eta_p^2 = .02$. The main effect of age was not significant, $F(1,150) = 1.25$, $p = .27$, $\eta_p^2 = .01$.

Analysis 2: Age and manifestation modulation of validity effects.

For this analysis we excluded the non-predictive locational cue condition. Cue validity effects were entered as a dependent measure in an ANOVA with age group (young vs. old) and cue manifestation (locational vs. symbolic) as independent variables.

Untransformed RTs validity effect. The ANOVA revealed a main effect of cue manifestation, $F(1,154) = 116.88$, $p < .001$, $\eta_p^2 = .43$, as well as an interaction between age group and cue manifestation, $F(1,154) = 3.35$, $p = .039$, $\eta_p^2 = .03$. Follow-up analysis indicated that for both age groups the validity effect was larger when the cue was locational than when it was symbolic, but this effect was smaller for young adults, $F(1,154) = 42.93$, $p < .001$, $\eta_p^2 = .22$, than for old adults, $F(1,154) = 74.71$, $p < .001$, $\eta_p^2 = .33$. The main effect of age was not significant, $F(1,154) = 1.73$, $p = .19$, $\eta_p^2 = .01$.

Proportional validity effect. Once again, this analysis replicated the results reported with the z-transformed RTs. The ANOVA revealed a main effects of age, $F(1,154) = 12.84$, $p < .001$, $\eta_p^2 = .08$, and of cue manifestation, $F(1,154) = 112.09$, $p < .001$, $\eta_p^2 = .42$. The cue validity effect was larger for younger adults than for older adults and following a locational cue than following a symbolic cue. There was interaction between the two factors, $F < 1$.



Supplementary Figure 1. Validity effect, calculated as (A) the difference between RTs on invalid trials and valid trials and as (B) the ratio between invalid and valid RTs, as a function of age-group and cue format. Analysis 1 reflects the two-way interaction between cue predictivity and age group. Analysis 2 reflects the two-way interaction between cue manifestation and age group. Error bars reflect 1 standard error.

Discussion

As can be seen from the analysis and from Supplementary Figure 1, analysis of untransformed RTs can give a wholly different picture of age differences in attentional orienting than an analysis that corrects for general slowing. Our original analysis (z-transformed RTs) and the proportional analysis (Supplementary Figure 1B) led us to conclude that relative to young adults, older adults gain less from predictivity, but are equally influenced by the cue's manifestation. In contrast, the analysis with the untransformed RTs (Supplementary Figure 1A) suggests that older adults gain just as much from predictivity, but are more strongly influenced by the cue's manifestation.

It might be telling that the results from the untransformed RTs make little sense from a theoretical stand point. The presence of orienting effects in the non-predictive locational condition indicates an exogenous shift of attention, but also an inability to filter out irrelevant (non-predictive) information. In contrast, the presence of orienting effects in the predictive conditions indicate an ability to endogenously shift attention towards a signal that is beneficial to the task at hand. Therefore, if we follow the age differences for each cue condition, the analysis of untransformed RTs suggest that old adults are at the same time *less* efficient in utilizing the cue's predictive information when it is irrelevant (i.e., rejecting the non-predictive locational cue); *more* efficient than young adults in utilizing predictive information when the cue is predictive; and *equally* efficient in utilizing predictive information when the cue is symbolic. We cannot find any theoretical framework that can explain this mixture of ability and inability. Therefore, coupled with the widely-agreed upon need for correcting for general slowing (e.g., Faust et al., 1999; Madden et al., 1992), we suggest that conclusions drawn from analysis of untransformed RTs should be rejected.

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