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PAPER

The modulation of visual orienting reflexes across the lifespan

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Abstract

The development of reflexive and voluntary shifts of visual attention, as well as relations between the two forms of shifting, were examined in three groups of children (5, 7, and 9 years old), one group of young adults (24 years old), and two groups of senior adults (young seniors with an average age of 69 years, and old seniors with an average age of 81 years). The task entailed response to the detection of a target (black dot) in one of four possible locations in the visual field. Relations between reflexive and voluntary shifts of attention were gauged by the degree to which flash and arrow facilitation and inhibition were observed in response to the presentation of both arrow and flash cues together in one trial. All age groups oriented reflexively in response to a flash cue and utilized the arrow cue to orient attention strategically. When flash and arrow cues were presented in quick succession and thereby competed for attention, the youngest children and oldest seniors were least efficient and flexible in their approach to the orienting task as they had difficulty modulating visual reflexes.

Introduction

Reflexive and voluntary orienting represent different processes in the shifting of attention that are both essential to selective attention (Brodeur, Trick & Enns, 1997; Enns & Trick, 2006). Reflexive shifts are activated by sensory events that command attention rapidly and involuntarily. During the brief period of reorienting to these salient events, other less important events are ignored (Abrams & Law, 2000). Voluntary orienting to a task-relevant event is under conscious control and demands mental effort. Reflexive and voluntary mechanisms of orienting need to be flexibly coordinated in order to visually explore the environment.

The veracity of these two contrasting constructs of orienting is supported in an extensive empirical literature (e.g. Brodeur & Enns, 1997; Hunt & Kingstone, 2003; Jonides & Irwin, 1981; Klein, 1994; Posner, 1980). Although both components involve the shifting of attention, their functional impact on human behavior differs considerably. Whereas voluntary orienting is sensitive to expectations with regard to the attended object and is therefore goal-directed, reflexive orienting is primarily involved in drawing attention to novel events by enhancing their visibility (Bartolomeo & Chokron, 2002; Egeth & Yantis, 1997; Macquistan, 1997). Yet, both these functions must be used in some integrated or coherent way for optimal attentional processing in the dynamic and complex visual environments that characterize the real world.

The uniqueness of each of these aspects of orienting is highlighted by differences between them with regard to developmental trajectories. Consistent with the notion of developmental progression from thought to action (Enns, Burack, Iarocci & Randolph, 2000; Werner, 1957), reflexive orienting appears to become entrenched in a child's repertoire prior to voluntary orienting. For example, infants attend automatically to events or objects (e.g. food source, parent) in the environment that are fundamental to their survival (Haith, Hazen & Goodman, 1988). The abilities to differentiate between task-relevant and task-irrelevant events and control orienting deliberately in order to effectively and efficiently complete a task develop later in childhood (Brodeur & Enns, 1997). By early and mid-adulthood, both reflexive and voluntary orienting mechanisms are fully developed and peak performance is attained across most visual exploratory tasks (Enns & Brodeur, 1989; Pearson & Lane, 1990). However, as adults age, the patterns of development appear to diverge again as reflexive orienting functions appear to be maintained, while the efficiency of controlled processes may decline (Folk & Hoyer, 1992; Hartley, Kieley & Slabach, 1990; Hoyer & Familant, 1987; Rafal & Henik, 1994).

One of the most common techniques for assessing the behavioral effects of orienting is the spatial-cueing paradigm in which the location of a subsequent target is cued in advance. Observers are able to use symbolic (e.g. arrow) or direct cues (e.g. flash of light) to shift their

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attention to a location designated by the cues. As a result of the attention shift, responses are typically faster and more accurate to the targets that occur at the validly cued (expected) locations as compared to targets that occur at the invalidly cued (unexpected) locations. Symbolic cues that are predictive as they occur 80% of the time in the same location as the subsequent target, engage voluntary orienting because the observer must deliberately interpret the cue and cue–target relation in order to shift attention effectively. Direct cues that do not predict the location of the target engage reflexive orienting processes since the salience of the cue and not the expectation drives the shift in attention. These cues are presented briefly (< 200 ms) with insufficient time for eye movements to occur and thus the measurement of orienting in this case is not confounded by ocular-motor efficiency.

Our goal was to explore whether a common link between relatively separate components of reflexive and voluntary orienting may be a regulatory mechanism that develops into late childhood and deteriorates late in life with normal aging. We reasoned that a visual reflex that alerted attention to salient events would be necessary early in life when there is a relative lack of experience with task-relevant cues. Later in development, however, voluntary orienting abilities dominate as the child acquires visual experience under a variety of conditions and is able to thoughtfully deliberate about task specific goals. At the peak of visual orienting ability in adulthood, a sophisticated executive system is hypothesized to regulate these complementary processes of reflexive and visual orienting and to effectively respond to visual contexts by coordinating among current demands and goals in relation to previous visual experiences. We suspect that peak efficiency of this executive or coordinating system is attained for a briefer period during the lifespan than of either the reflexive or voluntary processes individually, as it is reached later in childhood and is lost earlier in adulthood.

In order to examine the developmental trajectories of the efficiency of each of these aspects of orienting in isolation and in competition across the lifespan from 5 years to more than 80 years of age, we designed an orienting paradigm in which competing demands for attention were incorporated. Both *reflexive orienting* to non-predictive flashes in the near periphery of the visual field and *intentional orienting* to the same locations in response to directional arrows that appear at the center of gaze were examined alone and in relation to each other. Age differences across the lifespan in the coordination between reflexive and intentional orienting but not in the individual trajectories of the component orienting mechanisms would provide evidence for an executive regulatory mechanism that coordinates these separate but complementary processes.

Reflexive and voluntary orienting mechanisms

Reflexive and voluntary processes tap distinct resources (Klein, 1994), show unique age-related changes (Akhtar & Enns, 1989; Brodeur & Boden, 2000; Brodeur & Enns, 1997), and interact differently with other attentional processes (Brodeur *et al.*, 1997; Enns & Cameron, 1987). These distinctions are based on laboratory studies in which the cue type and cue–target spatial contingencies are manipulated within a task in order to measure the unique contribution of reflexive and voluntary orienting processes (Posner, 1980). In the case of reflexive orienting, the direct spatial cues, such as a brief flash at the target location, elicit an orienting effect even when they are *non-predictive*. Reflexive orienting is automatic, is thought to involve the superior colliculus (SC) in tandem with the parietal cortex (Coull, Frith, Büchel & Nobre, 2000; Rafal, Henik & Smith, 1991), and is implicated in the orienting to stimuli on the basis of attributes such as location, color, shape, and movement (Hahn & Kramer, 1995). It occurs without awareness or intention, and does not draw on the limited attentional resources that serve other higher-order cognitive processes (Yantis & Gibson, 1994). This process is typically activated by an abrupt physical event (i.e. flash of light) that moves attention to a peripheral location and commands attention rapidly and involuntarily for a short duration during which time other less important events are ignored (Abrams & Law, 2000). The effectiveness of a physical cue reaches its peak when the interval between the cue and the target (Stimulus Onset Asynchrony [SOA]) is approximately 100 to 200 ms, and then declines rapidly as the SOA increases (Ward, McDonald & Golestani, 1998).

The meaningfulness of the relation between the cue and the target is more significant in voluntary orienting as the efficiency of responding is contingent on whether the cue correctly indicates the subsequent target location. If the majority of the cues are valid, they are considered to be *predictive*. In this context, the difference in average reaction time (RT) on valid versus invalid trials is taken as an index of the orienting effect (Posner, 1980). Thus, voluntary orienting is a conscious and effortful process. It is thought to involve the frontal, inferior parietal and superior temporal areas (Coull *et al.*, 2000; Hopfinger, Buonocore & Mangun, 2000; Posner, 1995), which are also responsible for functions such as planning, coordinating multiple streams of information, and processing semantic information (Hahn & Kramer, 1995). Deliberate shifts may be activated by symbolic cues, task demands, and explicit instructions that require interpretation, attention, and mental effort that can interfere with other concurrent processes that also require attentional resources (Jonides & Irwin, 1981; Wright & Ward, 1998). Since the cue must be interpreted before a shift to the cued location can occur, the time course of voluntary orienting is longer than that required for reflexive orienting. The full effectiveness of voluntary orienting to a symbolic cue is not attained until approximately 300 ms after its onset; however, the cue continues to influence shifting behavior for more than 1 second after cue presentation, long after the effects of the peripheral cue disappear (Ward *et al.*, 1998).

The complexity of relation between the two types of orienting is highlighted when both are involved. For example, on a computer task, reflexive shifts can override voluntary shifts when the target is presented within 200 ms of peripheral cue onset (Hahn & Kramer, 1995; Müller & Rabbitt, 1989; Yantis & Jonides, 1990); however, the effect of the peripheral cue is diminished and the modulation of reflexes is restored as the SOA increases (Müller & Rabbitt, 1989; Theeuwes, 1991; Wright & Ward, 1998). The ability to modulate the reflexive aspect of attending is essential to preserving intentional attending to task-relevant information in the environment despite the appearance of stimuli that are physically salient and potentially distracting, but less task relevant.

Lifespan development of reflexive and voluntary orienting

The development of reflexive orienting is generally stable across the lifespan (Brodeur & Enns, 1997; Hartley & Kieley, 1995). Children of 4 years of age are able to process abrupt peripheral cues and orient their attention automatically to the spatial location (Akhtar & Enns, 1989; Lane & Pearson, 1983; Pearson & Lane, 1990). The efficiency of reflexive shifting, as indexed by RT differences between cued and noncued flash locations, improves through middle childhood (Akhtar & Enns, 1989; Enns & Brodeur, 1989; Pearson & Lane, 1990), and remains relatively stable through adulthood (Folk & Hoyer, 1992; Greenwood, Parasuraman & Haxby, 1993; Hartley & Kieley, 1995; Madden, 1990), and into the senior years up to 70 (Brodeur & Enns, 1997; Faust & Balota, 1997; Folk & Hoyer, 1992; Greenwood, Parasuraman & Alexander, 1997; Hartley *et al.*, 1990). However, senior adults older than 75 years (old seniors) exhibit greater costs in noncued flash locations compared to younger senior adults ranging in age from 65 to 75 years (Faust & Balota, 1997; Greenwood & Parasuraman, 1994), indicating that the speed of reflexive orienting appears to diminish only in the late 70s.

Whereas reflexive orienting remains stable with only a marginal decline in old age, the efficiency of voluntary orienting appears to develop later in children and decline sooner in seniors (Folk & Hoyer, 1992). At 6 years, children show strong benefits in response to symbolic cues at short SOAs (approximately 100–300 ms) – they are able to reorient attention in accordance with task demands as efficiently as adults (Pearson & Lane, 1990). However, at longer SOAs, children are less able to voluntarily sustain attention to a cued location (Brodeur & Enns, 1997). Young adults continue to show symbolic cue benefits across varying SOAs, demonstrating peak efficiency in voluntary orienting (Folk & Hoyer, 1992; Hahn & Kramer, 1995). Older adults appear to benefit more from symbolic cues at relatively longer SOAs of 500 ms (Brodeur & Enns, 1997; Folk & Hoyer, 1992; Hartley, 1993; Hoyer & Familant, 1987; Nissen & Corkin, 1985) with some exceptions (e.g. Folk & Hoyer, 1992; Hartley *et al.*, 1990).

A study of the coordination of reflexive and voluntary orienting

Changes in orienting efficiency through the lifespan occur within the context of dynamic environments in which voluntary and reflexive attending must both complement and compete with each other. Thus, we examined the efficiency of orienting from childhood through late adulthood with an experimental paradigm intended to assess the modulation of attentional reflexes during a voluntary orienting task. Voluntary orienting was examined by creating a context in which, at the beginning of each trial, participants could form a clear expectation of where the target was going to appear. This was done by beginning most trial sequences with a central arrow cue that predicted the location of the target with 75% accuracy. The effectiveness of the arrow cue therefore depended on participants forming an intention to use its spatial information. Reflexive orienting was examined with the presentation of a non-predictive peripheral flash cue, intended to capture attention reflexively at a particular spatial location. The modulation of this reflexive orienting effect, and its coordination with voluntary orienting, was examined in a situation in which the presentation of the predictive central arrow cue was followed shortly after by a non-predictive peripheral flash cue.

Over the course of development, the modulation of reflexes was expected to be most difficult for young children and old seniors as voluntary processes may be in transition – either developing or declining in efficiency at these ages. We included children aged 5, 7, and 9 years, young adults between the ages of 21 and 28 years, young senior adults between the ages of 60 and 74 years, and old senior adults between the ages of 75 and 91 years, because the most significant gains in attentional skills are observed between ages 5 and 7 years (Brodeur, 1990), smaller gains are apparent between age 9 years and young adulthood (Pearson & Lane, 1990), and, depending on the task, some abilities are maintained (e.g. Hartley & Kieley, 1995) or diminished (e.g. Greenwood *et al.*, 1993) among both younger and older senior adults.

Method

Participants

Three groups of children, with mean ages of 5.7 years (n = 20, SD = .28), 7.3 years (n = 21, SD = .32), and 9 years (n = 24, SD = .15), were recruited from a Montreal public school. The group of young adults was composed of McGill University graduate students with a mean age of 24.5 years (n = 18, SD = 2.26). The two groups of senior adults with mean ages of 69.1 (n = 16, SD = 3.99) and 81.3 (n = 14, SD = 4.86) years were recruited from an independent living residence for seniors and a drop-in center for seniors. All the participants were asked about whether they had been diagnosed with any serious neurological deficits as well as visual impairments, including visual acuity that cannot be corrected-to-normal, cataracts, and glaucoma, and they were excluded if they responded yes to any of these conditions.

We complied with APA ethical standards in the treatment of all participants and ensured that each participant fully understood the study and all its components. We received informed consent verbally and in writing from each participant or their legal caregiver where applicable before beginning the procedures. Participants were reminded that they could withdraw from the study at any time without consequences.

Stimuli and apparatus

A simple detection task was developed using Vscope software (Enns, Ochs & Rensink, 1990). Stimulus presentation, feedback, and data collection were controlled by a Macintosh (Power Mac G3) computer connected to a 15-inch Hyundai Delux scan monitor. The participants were seated 100 cm from the screen with one hand resting on the space bar. The target was a round disk (black, 0.5° in diameter) that appeared in the center of one of the four target location markers. The target location markers were four outline square boxes (1.2° per side, lines 2 pixels in width, black on a white screen) positioned at the corners of an imaginary square 2.0° from the center of the screen. Two types of directional cues were presented at the center of the four target location markers. First, a central cue was presented consisting of either two double-headed arrows (neutral or non-directional cue) or a single arrow (black, 0.06° in length) that was correctly predictive of the target location 75% of the time. These arrow cues were presented for 150 ms. To avoid measuring responses that were anticipatory rather than perceptual, following the presentation of the first display in each trial sequence (i.e. the directional or neutral arrow cue) there was an uncertain amount of time that elapsed before the target appeared (i.e. either 280 or 980 ms). In the next display frame, a flash cue could appear for 30 ms (or no flash). The peripheral flash cue was a 30 ms blackening (an additional 2 pixels line thickness) of one of the four target location markers (black, 0.03°). Its location was not predictive of the target, as it occurred in the same location as the target on a random 25% of the trials in which it was presented. The next phase was an interval of either 100 ms or 800 ms during which the display did not change. The two SOAs were used in order to examine the time course of orienting to these two cues. The target was presented and remained on until the participant responded or until 3000 ms elapsed. A response miss was defined as no response within the 3000 ms time frame. However, on 5% of the trials (10/192), no response was the correct decision because no target was presented. Responses on these trials were false alarms and their frequency indexed whether participants were following task instructions. Misses and false alarm error data ensured that all participants were completely 'on task'.

Examples of the conditions are presented in Figure 1. The participants performed the detection task by depressing the space bar on a computer keyboard, using their dominant hand, whenever they saw a disc (black, 0.5° in diameter) appear in one of the display boxes. Following the participant's response, one of three possible feedback stimuli were presented at fixation for 500 ms. A plus sign (black, 0.1°) indicated a correct response, a minus sign (black, 0.1°) indicated a false alarm response on no target trials, and an empty circle (outline black, 0.5° in diameter) indicated that no response had been made for 3000 ms following the appearance of a target.

Design and procedure

Each participant was administered 192 trials divided into two blocks separated by a 5-minute break. Sixty percent (116/192) of the trials included both a directional arrow cue and a flash cue (both cues), 16% (30/192) included a directional arrow cue but no flash cue (arrow only), and 16% (30/192) included a flash cue with a neutral arrow cue (flash only), 3% (6/192) included no cue at all (no cue), and 5% (10/192) included no target (catch trials). Half of the trials in each condition were involved to each of the two intervals (100 ms and 800 ms). Within each block, trials were selected randomly, without replacement, from the 192 different types of trials.

The participants were seated 100 cm from the computer screen and tested individually in one 15–20 minute session. The experimenter showed the participants a drawing of the four possible target locations and the target in the

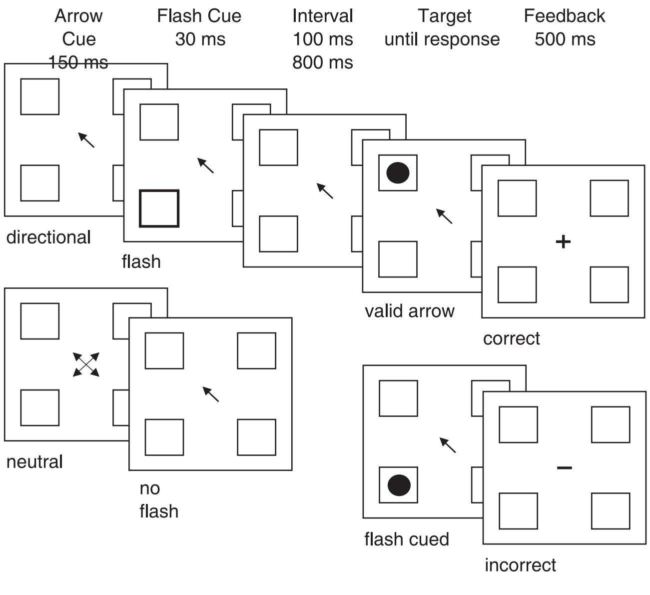

Figure 1 *Illustration of the display sequences and several different cue–interval–target combinations possible in the experiment.*

location indicated by the arrow. The experimenter then explained that four boxes would appear on the computer screen and that a black dot would appear in one of these boxes. The participants were asked to press on the space bar as soon as they saw the black dot on the screen, but not to press on the space bar when the black dot was not present. They were informed that the black dot would appear in only one of the four boxes on the screen.

The participants were administered two sets of 10 practice trials. During the practice trials, the participants were provided verbal feedback on their performance. Incorrect responses were followed by a repetition of the original instructions and encouragement to continue. The criterion for inclusion was 90% correct (i.e. 2 errors), a rate of performance that is better than chance and a level of accuracy that is adequate for studies of simple detection. No participant was excluded after the practice session, as accuracy was generally high for everyone. Before beginning the experimental trials, the experimenter reminded the participants to fix their gaze on the center of the screen during the beginning of each trial.

Results

The trials were subdivided so that five different analyses of response time (RT) could be conducted. One, in order to examine the general level of vigilance to the task, the mean correct RT was calculated for each participant, subdivided into four consecutive sets of 48 trials. Two, performance on trials with no cue were compared to trials with only a flash cue, trials with only an arrow cue, and trials with both types of cue, in order to test for any overall group differences in general alerting caused by the mere presence of either the flash or the arrow cues. Three, reflexive orienting was indexed by examining all trials that included a flash cue. The flashes could be either in the same location as the target (cued) or in a different location (noncued), but were not predictive. They could also occur either 100 ms or 800 ms before the target (Interval) and could be the only cue or preceded by a predictive arrow cue (Context). Four, voluntary orienting was examined for all trials that included a predictive arrow cue. These arrows were either spatially valid (correctly predicting the location of the target) or invalid (incorrectly predicting a different location). The participants were expected to use the arrows to guide their attention and show a speeded RT on valid arrow trials compared to invalid arrow trials. The arrows could also occur either 280 ms or 980 ms before the target (Interval) and could be the only cue or followed by a flash cue (Context). Five, visual reflex modulation was measured on the trials that included both the predictive arrow cue followed by a non-predictive flash cue. Reflex modulation was operationalized as a Flash Cue Difference Score (Flash Noncued RT minus Flash Cued RT), which was positive when the presence of the flash enhanced target detection and negative when the presence of the flash slowed target detection. If the Flash Cue Difference Score varied as a function of whether the arrow cue was valid or invalid, it would indicate that the visual reflexes were being modulated by the voluntary intention to use the spatial information contained in the arrow cue. Based on previous evidence that young children and old senior adults may be vulnerable to distraction by irrelevant peripheral cues (Brodeur & Enns, 1997), we suspected that they would have the most difficulty modulating reflexive orienting.

Our primary interest was in the speed with which the participants were able to detect the target under the various cue and interval conditions in the experiment. However, preliminary analyses of the error data and of the overall mean response time (RT) data were necessary to ensure that the comparison of the speed of spatial orienting between groups was not confounded by differences in either response accuracy, overall response speed, or vigilance to the task. Unless otherwise indicated, an alpha level of .05 was used for all statistical tests and the F-values that are reported were corrected for possible heterogeneity of variance with the Greenhouse-Giesser solution. All linear and quadratic trends that are reported yielded the same results when age was treated as either a monotonic (groups 1–5) or as a real-value variable (5, 7, 9, 24, 69, 81 years).

Accuracy

False Alarms (incorrectly responding on the 5% of trials when no target was presented) and Misses (failures to respond in the 3 second time window we offered the participants on the 95% of trials containing a target) were each examined with analyses of variance (ANOVA) of the between-participant factor of age. Overall, errors (both false alarms and misses) were rare in all age groups. Differences with age were found for false alarms, as the children committed more of these errors (5 years = 6.5%, 7 years = 3.8%, 9 years = 6.7%) than either young adults (24 years = 0.6%) or senior adults (69 years = 0.6%, 81 years = 1.4%), $F(5, 109) = 3.72$, $MSE = 0.009$, $p < .01$. However, a speed–accuracy tradeoff was not indicated as the mean RT of the children was also larger. This means that the false alarm data supported the RT data; longer RT reflected generally reduced performance and not simply a tradeoff for higher accuracy in responding. Very few misses were committed by any participants (mean group miss rate < 1.0%) and no group differences were found on this measure, $F(5, 109) < 1.0$, $p > .70$. False alarm rates could not be analyzed for cue–target relations because there was no target. Thus, no ANOVAs comparable to those for RT were possible.

Vigilance

The ability to sustain interest in the task over the testing session was assessed by examining the mean correct RTs

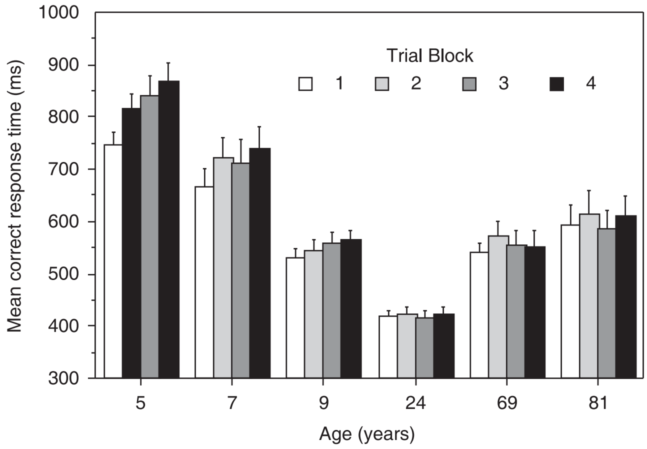

Figure 2 *An index of vigilance to the task: Correct RT (ms) as a function of age and grouped into four consecutive sets of 48 trials.*

in four consecutive sets of 48 trials. These data are presented in Figure 2 for the six groups of participants. As is evident in this graph, mean RT is generally U-shaped over the lifespan, and children experience more difficulty sustaining high levels of performance than adults. These observations were confirmed by statistical analyses.

An ANOVA on the between-participants factor of age and the within-participant factor of trial block (1, 2, 3, 4) revealed a significant main effect of age, $F(5, 109) = 28.18$, MSE = 60115.80, $p < .001$, and a significant main effect of trial block, $F(3, 327) = 11.95$, MSE = 3468.50, $p < .001$. These main effects were tempered by a significant interaction, $F(15, 327) = 2.75$, MSE = 3468.50, $p < .01$, that reflected that the RT of the younger participants tended to get longer over time (each linear trend, $p < .01$), whereas the RT of the three groups of adults did not change during the testing session (all trends, $p > .10$).

General alerting

The temporal alerting influence of the cues, independent of their role in spatial orienting, was examined by comparing mean correct RT for trials with no cues (3% of trials), only arrow cues (16% of trials), only flash cues (16% of trials), and both types of cue (60% of trials). These data are presented in Figure 3 for the six groups of participants.

This graph indicates that, in addition to the U-shaped effect of age on mean RT, slower responses tended to be found on trials with no cues (mean RT = 663 ms) than trials with only flash cues (mean RT = 641 ms), only arrow cues (mean RT = 620 ms), or with both cues (mean RT = 613 ms). This generally slower RT on no cue trials could, in part, be due to their infrequency. Relative frequency differences could also contribute to the difference in RT between single cue and combined cue trials. However, these effects did not differ between age groups, suggesting that this variable had a constant influence on all participants.

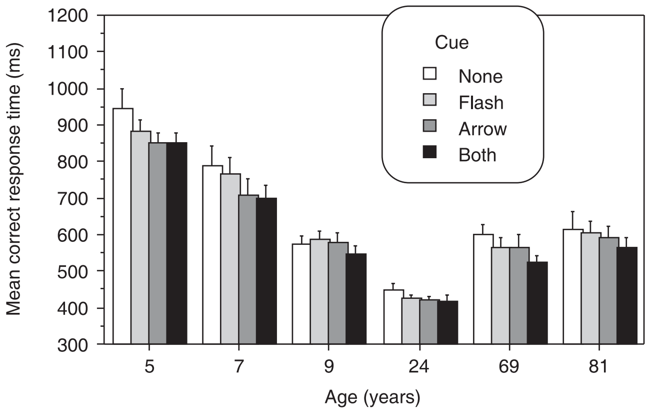

Figure 3 *An index of general alerting caused by the cues: Correct RT (ms) as a function of cue type and across ages.*

An ANOVA on the between-participants factor of age and the within-participant factor of trial cue type (none, arrow, flash, both) revealed only a significant main effect of cue type, $F(3, 327) = 5.96$, MSE = 17651.89, $p < .001$, in addition to the main effect of age already described.

Reflexive orienting

On the 76% of trials that included a non-predictive flash cue (16% with only a flash cue + 60% with both a flash and an arrow), the tendency for the participants to attend reflexively to the location indicated by the flash was examined with a focus on the Flash Cueing effect (Flash Noncued RT – Flash Cued RT) as the main dependent measure. These data are presented in Figure 4.

An ANOVA indicated a significant main effect of interval, $F(1, 107) = 8.21$, MSE = 19471.75, $p < .01$, reflecting a generally larger flash cue effect for the 100 ms interval than the 800 ms interval. No other effects were significant, including those of age, presence of arrow cue, or interactions among these factors. The quadratic trend for age hinted at in the means of the 800 ms interval was not significant ($p > .10$).

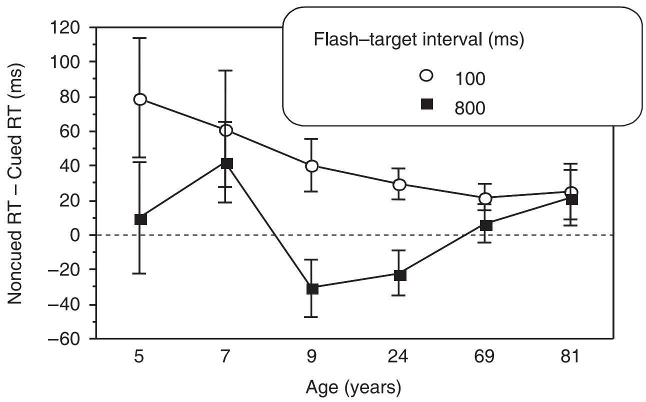

Figure 4 *An index of reflexive orienting: Difference scores (in ms) comparing flash noncued and flash cued as a function of flash–target interval and across ages.*

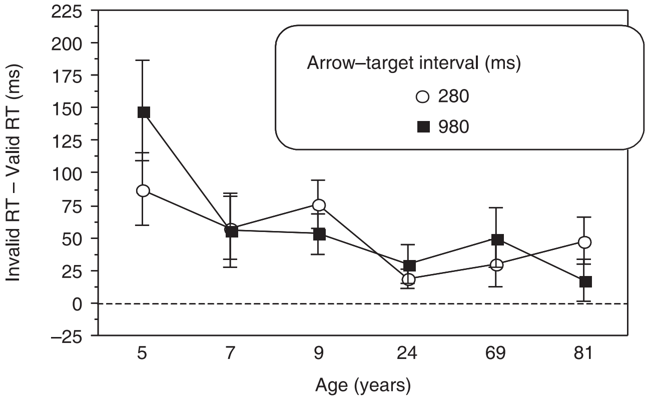

Figure 5 *An index of voluntary orienting: Difference scores (in ms) comparing invalid and valid arrows as a function of arrow–target interval and across ages.*

Voluntary orienting

On the 76% of trials that included a predictive arrow cue (16% only an arrow + 60% both a flash and an arrow), the ability of the participants to attend voluntarily to the location indicated by the arrow was examined with a focus on the Arrow Validity Score (Invalid Arrow RT – Valid Arrow RT) as the main dependent measure. The Arrow Validity Score is shown in Figure 5, as a function of age and flash cue interval. An ANOVA indicated that only the main effect of age was significant, $F(5, 107) = 3.55$, MSE = 24313.51, $p < .01$, and this was due entirely to a larger arrow cueing effect for the 5-year-olds than the other age groups, Fisher's LSD test, $p < .05$. No other effects were significant.

Visual reflex modulation

On the 60% of trials that included both a predictive arrow cue and a non-predictive flash cue, the interactions among these cue types were examined with a focus on the Flash Cueing Score (Flash Noncued RT – Flash Cued RT) as the main dependent measure. This is an index of reflexive spatial orienting that is generally positive (reflecting cue facilitation) when the flash–cue interval is short (100 ms) and generally negative (reflecting cue inhibition) when the flash–cue interval is long (800 ms). This flash effect is shown in Figure 6 as a function of both age and arrow validity. Several effects are evident in these graphs.

One, the similarity among the different age groups was greater when the arrow cue was valid (left panel) as compared to when it was invalid (right panel). Two, the flash effects tended to be greater (both facilitation at the 100 ms interval and inhibition at the 800 ms interval) among the youngest and the oldest age groups. This is seen in the U-shaped trends in the size of the flash effects over age with a positive U-shape for the 100 ms trials and an inverted U-shape for the 800 ms trials. Three, the U-shaped trends over the lifespan for both facilitation at 100 ms and inhibition at 800 ms were larger when the arrow cue was invalid (right panel) than when it was valid (left panel).

The observations were supported by the following statistical analyses. The correct RT data were analyzed with a mixed-design ANOVA involving the between-participants factor of age and the within-participant factors of Flash (Noncued, Cued), Arrow (Invalid, Valid), and Flash–Target Interval (100 ms, 800 ms). This analysis indicated that the highest order interaction was significant, Age × Flash × Arrow × SOA, $F(5, 107) = 4.42$, MSE = 11268.98, $p < .001$. This significant interaction justified the examination of cue interactions at each of the different ages and flash–target intervals. The main effects of arrow validity, $F(1, 107) = 41.60$, MSE = 17007.19, $p < .0001$, indicated generally faster RT for valid than for invalid arrow cues, and the flash cue × interval interaction, $F(1, 107) = 17.03$, MSE = 9019.24, $p < .001$, reflected generally faster RT for cued than noncued flash locations at the 100 ms interval and generally slower RT for cued than noncued flash locations at the 800 ms interval.

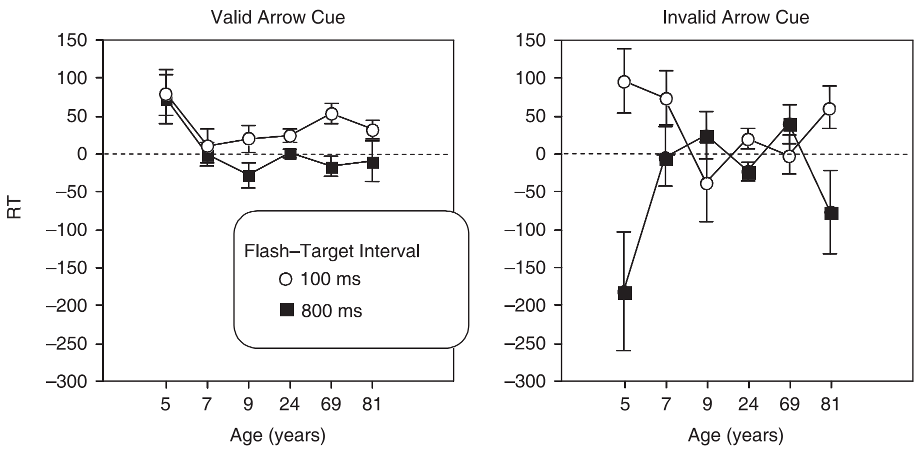

Figure 6 *An index of reflex modulation: Difference scores (in ms) comparing flash noncued and flash cued as a function of arrow validity, interval and age.*

The ANOVA for valid arrows indicated significant effects of age, $F(5, 107) = 4.85$, MSE = 7013.61, $p < .001$, indicating larger flash effects for the 5-year-olds than all other groups, and interval, $F(5, 107) = 4.42$, MSE = 11268.98, $p < .001$, indicating generally larger flash effects at the 100 ms than the 800 ms interval. The interaction was not significant, $F < 1.0$, MSE = 7013.61, $p > .73$.

The same ANOVA for the invalid arrows revealed no main effect of age, $F < 1.0$, MSE = 38533.08, $p > .62$, but an interaction of Age × Interval, $F(5, 107) = 4.87$, MSE = 31881.76, $p < .001$. Further inspection of this interaction revealed a significant quadratic component in the simple effect of age for both the 100 ms trials, $F(1, 107) = 4.82$, MSE = 28976.95, $p < .03$, and the 800 ms trials, $F(1, 107) = 9.61$, MSE = 41437.89, $p < .003$. These quadratic components correspond to the U-shaped trend seen over age for the facilitating effects of the flashes at 100 ms and the inverted U-shaped trend seen over age for the inhibitory effects of the flashes at 800 ms.

Discussion

The findings from this study suggest that younger children and older seniors are less able than those in the more intermediate age groups to coordinate among processes and modulate reflexive processes that can interfere with intentional attending. Less than optimal efficiency in the orienting of attention was found among children aged 5 years and older seniors in their 80s when both reflexive and voluntary orienting were involved in processing, although the functioning on each of these types of orienting was optimal in isolation. Like the older groups of children and younger groups of adults, the members of these two disparate age groups were able to reflexively orient to non-predictive flash cues, voluntarily orient to predictive arrow cues, and even to modulate reflexes when the flash and arrow cues did not compete for their attention. However, they differed from the others with regard to the ability to modulate reflexes when the flash and arrow cues competed for their attention. Whereas the children aged 7 and 9 years and the young adults readily recovered from a misleading cue that directed their attention to an unexpected location, the youngest children and oldest seniors showed less modulation in both the case of early facilitation and of late inhibition to the flash cue.

Similarities in performance across ages

Reflexive orienting to the non-predictive flash was observed in all age groups, with a larger facilitation effect at 100 ms than 800 ms. Voluntary orienting to the predictive arrow was also found among all age groups. Consistent with previous findings (Enns & Akhtar, 1989), younger children showed larger arrow effects than older children and adults. Whereas voluntary orienting is generally regarded as an effortful and resource demanding process (Corbetta, Miezin, Shulman & Petersen, 1993; Jonides & Irwin, 1981), the present data suggest that it seems relatively unaffected by normal aging.

Differences in performance across ages

Age differences emerged in the flash and arrow cue condition in which reflexive processes needed to be modulated in order to allow for optimal efficiency of the intention to voluntary orienting to achieve a specific goal. These differences involved the suppression of task-irrelevant information when peripheral flash and central arrow cues competed for attention. Visual reflex modulation was indexed by the ability to use predictive arrows to attenuate the effects of a non-predictive flash cue. The ability to modulate reflexive orienting was noted across all age groups and was evidenced by the finding that the smallest flash facilitation and inhibition effects were evident with valid arrows. However, age differences were noted on the percentage of invalid trials in which the arrow did not predict the target location. Here, the early facilitation and later inhibition effects of reflexive orienting were largest for the youngest and oldest age groups.

The ability to modulate reflexive orienting varies with age. When the intention to voluntarily orient to a location is successful, then persons of all ages benefit from the combined cues indicating the same target location, with this combined cue effect vanishing by 800 ms. However, the age effects were most evident when voluntary orienting was not successful, and the target appeared somewhere other than where it was expected. Within this context, the older children and young adults were able to attenuate (i.e. modulate) the effects of the flash cue on reflexively orienting to the target and reflexively inhibiting orienting to a previous location, whereas the youngest children and eldest seniors were no longer able to effectively modulate their orienting reflex. Specifically, when targets did not appear where they were expected to appear, the youngest children and oldest seniors (as compared to the other age groups) behaved with an exaggerated response to the flash cue as indicated by reflexively orienting to the flash cue early in the cue–target interval and reflexively orienting away from it later in the cue–target interval, whereas the other age groups remained more flexible in their orientation to the target. The implications of the reflex modulation findings are that the agile observer appears to executively control the reflexive response to a salient yet misleading attentional event and maintain goal-directed orienting behavior. Thus, when the observer is confronted with a salient and uninformative event (non-predictive flash cue) within a context of expectation to orient to a predictable location (predictive arrow cue), the automatic response to orient to the salient event is modulated by intentions to orient elsewhere. However, the youngest children and oldest seniors were less able to executively control the orienting reflex and, therefore, unintentionally detracted from the task-relevant orienting response.

Conclusions

The findings suggest that difficulties in visual orienting to real world complex and dynamic environments among the younger children and older seniors are a result of the way they regulate component processes in a task-relevant way and are not due to deficiencies in the functioning of either of the orienting components. In this study, both the youngest observers (5-year-olds) whose orienting abilities are emerging, and the eldest observers (average age of 81 years) whose orienting abilities are naturally declining, showed less efficient deployment of spatial attention than young adults. The similar orienting difficulties at very different points in development appear to involve similar executive control limitations and highlight the distinction between higher-order control of visual cognition and lower-order visual reflexes (Shiffrin & Schneider, 1977). The evidence suggests that the common link between these relatively separate components of orienting may be a regulatory mechanism that develops into late childhood and deteriorates late in life with normal aging. From a developmental perspective, a visual reflex that alerts attention to salient events early in life is likely to be quite adaptive for a visual system that lacks experience with task-relevant cues. A little later, voluntary orienting abilities develop as the child acquires visual experience under a variety of conditions and is able to thoughtfully deliberate about task specific goals. An even more sophisticated executive system emerges to regulate these complementary processes of reflexive and visual orienting and to effectively respond to visual contexts by coordinating among current demands and goals in relation to previous visual experiences. Peak efficiency of this executive or coordinating system is attained for a briefer period during the lifespan than of either the reflexive or voluntary processes individually, as it is reached later in childhood and lost earlier in adulthood.

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