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Lifespan Changes in Attention Revisited: Everyday Visual Search

Allison A. Brennan
Simon Fraser University

Alison J. Bruderer, Teresa Liu-Ambrose, and Todd C. Handy
University of British Columbia

James T. Enns
University of British Columbia and University of Western Australia

This study compared visual search under everyday conditions among participants across the life span (healthy participants in 4 groups, with average age of 6 years, 8 years, 22 years, and 75 years, and 1 group averaging 73 years with a history of falling). The task involved opening a door and stepping into a room find 1 of 4 everyday objects (apple, golf ball, coffee can, toy penguin) visible on shelves. The background for this study included 2 well-cited laboratory studies that pointed to different cognitive mechanisms underlying each end of the U-shaped pattern of visual search over the life span (Hommel et al., 2004; Trick & Enns, 1998). The results recapitulated some of the main findings of the laboratory study (e.g., a U-shaped function, dissociable factors for maturation and aging), but there were several unique findings. These included large differences in the baseline salience of common objects at different ages, visual eccentricity effects that were unique to aging, and visual field effects that interacted strongly with age. These findings highlight the importance of studying cognitive processes in more natural settings, where factors such as personal relevance, life history, and bodily contributions to cognition (e.g., limb, head, and body movements) are more readily revealed.

Keywords: life span, attention, visual search, children, fallers

It is common for studies of visual search to begin with an anecdote about how search is an important topic because we often find ourselves looking for misplaced possessions. The studies then typically move on to describe a task in which participants press one of two keys after looking for colored shapes on a small-screen computer, or after looking for a common object in a photo (e.g., a toaster in a kitchen scene). In the present study, we wish to take more seriously the conditions under which everyday searches are made. Instead of searching for colored shapes or for objects in photos, we study participants searching and responding as they would in a social setting where they are the "seeker" and the experimenter is a "hider." This means seekers will be searching through a visual environment that is larger than can be encompassed with a single glance and that they point to the target when they find it. Although the object will be in view (not occluded by other objects), participants will be able to move their bodies, limbs, and eyes quite naturally. As a trade-off for what some will see as a lack of experimental control, we hope to say something meaningful about how visual search differs across the life span when it is conducted under the conditions that previous studies have assumed their results will generalize to, but have never tested.

The Conditions of Everyday Visual Search

Everyday visual searches are, of course, as different from one another as the conditions that led to the need for search in the first place. Yet, what many everyday searches have in common is that they take place in the three-dimensional world of surfaces, objects, and active motion by the seeker. One important consequence is that the search environment is much larger than the scope of a single fixation of the eye, which has been typical for many studies of search on a computer screen. Do the findings of previous studies with small screens generalize to the large-scale environments of everyday search, where seekers can move their eyes, heads, and bodies through space in order to find the targets of their search? Some researchers have used mobile eye trackers in a variety of real-world contexts to explore these questions in college-aged participants (Foulsham, Walker, & Kingstone, 2011; Freeth, Foulsham, & Kingstone, 2013; Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Tatler, Kirtley, Macdonald, Mitchell, & Savage, 2014). Other researchers videotaped participants in search tasks and invited a second group of participants who were unaware of both the search condition and the objective performance levels to rate the behavior of searching participants (Brennan et al., 2011). These authors reported that body and head movements were

Allison A. Brennan, Department of Psychology, Simon Fraser University; Alison J. Bruderer, School of Audiology and Speech Sciences, University of British Columbia; Teresa Liu-Ambrose, Department of Physical Therapy, University of British Columbia; Todd C. Handy, Department of Psychology, University of British Columbia; James T. Enns, Department of Psychology, University of British Columbia, and Department of Psychology, University of Western Australia.

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Correspondence concerning this article should be addressed to James T. Enns, Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, BC, Canada V6T 1Z4. E-mail: jenns@psych.ubc.ca

much better predictors of efficient visual search than eye movements. They also reported that a significant portion of the variance in search time and accuracy, between searchers of different ability, could be accounted for by the way in which seekers moved and in the emotional expressions they made when looking for a target. Yet, with respect to the present study, it is notable that studies of search in everyday environments have not yet compared searchers across the life span.

A second distinctive feature of everyday search is that the targets and distractors (potential targets that must be rejected from consideration) are meaningful and complex three-dimensional objects. This stands in sharp contrast to the oft-reported search for colored geometric shapes (e.g., Wolfe, 1998), pictures of items with emotional connotations (e.g., snakes; LoBue & DeLoache, 2008), and photos of natural scenes (e.g., Foulsham & Underwood, 2007). This is an important difference because of its implication to theories of attentional selection. The conventional view holds that attentional selection precedes the assignment of meaning and value to stimuli that are being selected for more detailed processing (Posner, 1978; Treisman & Gelade, 1980). Researchers have typically used carefully controlled experiments (e.g., with coloured shapes) to explore questions of how the similarity of targets and distractors, or the number of distractors (set size), affect attentional allocation. More recently a dynamic view of attentional selection is under consideration, one where the gate of attention is determined by a complex web of considerations that include the role of emotion, personal relevance, motivation, and reward history (Anderson, 2011; Awh, Belopolsky, & Theeuwes, 2012; Ristic & Enns, 2015; Krauzlis et al., 2014). In this view, attentional selection is as much the outcome of these factors as it is a gateway to them. To explore questions of this nature, researchers will have to move from target objects that are devoid of meaning and/or are mere depictions of emotional content to those that more closely approximate the conditions of everyday life.

A third feature of everyday search is that seekers bring their personal background and life experience to the task. For example, there are gender differences in the attention of neonates, with male babies looking relatively longer to mechanical objects and female babies relatively longer to human faces when these two classes are put into direct competition (Connellan et al., 2000). There are also cultural influences in visual scanning patterns (Abed, 1991), with a left to right bias in North American culture that mirrors learned strategies for negotiating traffic and reading. Health status can also make a difference, with older adults with a history of falling exhibiting left visual field deficits during visual search on a small screen (Nagamatsu, Liu-Ambrose, Carolan, & Handy, 2009; Nagamatsu, Munkacsy, Liu-Ambrose, & Handy, 2013).

Overview of the Present Study

Participants in this study searched for four everyday objects (apple, golf ball, coffee can, toy penguin) in a room with a table and shelves cluttered with other everyday objects. The search environment and targets are illustrated in Figure 1. After showing the target object to the participant in the waiting room, the experimenter entered the search room and positioned the target behind a closed door, following a script that ensured that target identity, location, and the relative amount of clutter surrounding the target was distributed equally across trials and participants. The experimenter then returned to the waiting room. To begin searching, participants opened the door into the room, toward the left, before stepping into the cluttered room. From a standing position in the doorway, they then made body, head, and eye movements until they located the target. Once they detected the target, they raised their arm to point to its location and to indicate to the experimenter than they found it. Their behavior was recorded on video by a small camera on the right hand side of the room, which was then used to measure the elapsed time of various components of the search episode.

Figure 1. Illustration of the search environment, with the four target objects in the experiment depicted below (shown larger than they appeared in the scene). On each trial the experimenter would show one of these targets to the participant in the waiting room, before going into the room to place the object in the scene. After leaving the room and closing the door, the experimenter asked the participant to enter the room and find the target as quickly as possible. The coffee can is the target in this image. See the online article for the color version of this figure.

The goal of this study was to compare everyday visual search across the life span in order to address five central questions:

Search Environment

How do the findings of past studies using small visual field environments and keyboard responses compare with visual search under more the realistic conditions of large visual fields and pointing responses? Past theoretical accounts of life span search have at times appealed to global mechanisms for why the function is U-shaped, meaning that both young children and older adults search less efficiently than healthy young adults. Among the two most prominent proposals for such mechanisms are generalized neuronal slowing (Cerella, 1985; Kail, 1991; Salthouse, 1996) and a reduced ability to engage in perceptual inhibition (Hasher & Zacks, 1988; Tipper, 1991). But there have also been results and theoretical speculation implying that different mechanisms are responsible for reduced search efficiency at each end of the life span (Hommel et al., 2004; Trick & Enns, 1998; Trick, Enns, & Brodeur, 1996). If global mechanisms of life span apply to everyday search, then we would expect the U-shaped pattern of search efficiency to apply to all targets and locations. On the other hand, if different results occur for targets and locations across the life span, then it would support more nuanced theories claiming separate mechanisms for maturation and senescence in search.

Everyday Objects

How do the findings of visual search based on geometric shapes compare to search for real, three-dimensional, common, household items? We chose a range of common objects as the targets in our search task, to include a target that might hold intrinsically greater interest for children than other groups (e.g., toy penguin) and a target that might be of greater interest to adults than children (e.g., coffee can). The golf ball and the apple were initially chosen because they differed in relative size from one another, and as such may reveal differences with age in sensitivity to small objects. As the results will show, the apple turned out to be especially salient to participants in all groups, suggesting its status as food or its color may have played a role in the search results.

Clutter

How do past laboratory findings with respect to visual clutter on children and elderly adults relate to search under more realistic conditions? Past life span studies have pointed to both the concepts of a reduced useful field of view (Ball et al., 1988) and increased crowding (Bouma, 1970) to account for age differences in search ability. However, on the face of it, this poses a paradox because, although a reduced field of view implies something akin to "tunnel vision" and therefore a neglect of the visual surround, *crowding* refers to the difficulty of visual identification precisely when a target object is surrounded by other objects. How is it that neglected regions of the visual field are especially distracting? As Enns and Girgus (1985) pointed out in a study of perceptual grouping in children, if children are less able than adults to both *segregate* visual spatial information and to integrate visual information over space, then their difference from adults is more likely to be an issue of strategic control, rather than an issue with either segregation or integration per se. In the present study, we varied the relative amount of clutter surrounding the target objects to determine whether either end of the U-shaped life span pattern was more adversely affected by being placed in the centre of the shelves (implicating greater crowding) or near the periphery (implicating less crowding).

Visual Field

Are there differences across the life span in the biases of participants to inspect one side of the visual field at the expense of the other side? This is a largely unexplored question in the background literature on life span search, but we could think of at least three reasons why it might be important. These reasons included (a) developmental and aging effects on visual field specialization, (b) the effects of environment and culture on strategies for exploration, and (c) bodily posture effects associated with development, aging, and task requirements (i.e., opening the door to the left and entering a room to look for an object). Mirroring the findings from previous studies, which have been quite mixed (Brooks, 2014; Nuthmann & Matthias, 2014), our own results were more complicated than any of these simple hypotheses and will clearly deserve further work to be clarified.

Healthy Versus Vulnerable Aging

Is an everyday search task sensitive to the cognitive differences between participants who are aging with generally good health and those that show signs of vulnerability to cognitive impairment through a history of falling? Past research has indicated that older adults with a history of falling also have measurable behavioral and electrophysiological differences on laboratory tasks of visual attention (Liu-Ambrose et al., 2008; Nagamatsu et al., 2009). Here we made a similar comparison in order to determine whether the attention impairments of fallers are demonstrable in a brief task that closely resembles how attention is used in everyday life.

Method

Participants

Fifty-four participants in all were recruited for this study in order to represent at least 10 individuals in each of five groups. The data from four participants were incomplete or not included (one 6-year old failed to complete the search task, three elderly participants had search times that exceeded their peers by more than two standard deviations). This left 10 participants in the following groups: children 5–6 years of age (M = 6.1 years, SD = .77, five girls), children 7–9 years of age (M = 8.2 years, SD = .89, five girls), young adults (M = 22 years, SD = 1.7 years, eight women), older healthy adults (M = 74.7 years, SD = 3.65, all women) and older adults with a reported history of having fallen two times in the past 12 months (M = 73.2 years, SD = 2.7 years, all women). For simplicity we will use the labels 6 years, 8 years, young adults, healthy seniors, and senior-fallers.

The children were recruited from a community sample in Vancouver, BC and parents received monetary compensation for their child's participation. Children gave informed consent verbally, along with the written consent of their parents. Young adults were undergraduate students at the University of British Columbia who received monetary compensation or course credit for participating. Seniors were recruited from a community sample in Vancouver, BC as part of a larger cross-sectional study comparing cognitive profiles of senior fallers and nonfallers during an exercise intervention. Falls history was reported based on subjective recall and corroborated by an immediate family memory or close friend. All older adults had intact cognitive functioning, as indicated by a Mini Mental State Examination score greater than 24 points. The adults all provided written informed consent and were otherwise treated in accordance with APA standards. The University of British Columbia Office of Research Ethics approved this research.

Stimuli and Apparatus

The search task is illustrated in Figure 1. All participants searched for targets in the same room, consisting of a small empty office that contained a table holding shelves that were populated with distractor objects commonly found in a home or office. The dimensions of the room were approximately 3.05 m wide, 3.66 m long, and 2.44 m high. This meant the active search environment, which included all shelves above the table top, subtended about 44 horizontal and 30 vertical degrees of visual angle. A digital video camera, on a tripod to the right of the shelves, recorded the upper body and head of participants, and they were informed that we would use this recording to measure how quickly they found the targets.

Children and senior adult participants each completed a total of 16 search trials, sampled from a total of 40 different search configurations. These 16 trials involved four target objects (apple, golf ball, coffee can, toy penguin) placed in each of four different spatial quadrants of the shelves. Within a quadrant, each target was randomly placed in either a central location (in the eight central cubicles) or in a peripheral location (in the outside cubicles). The young adults searched through more search configurations than the other groups, because they were given a fifth target (vinegar bottle) that was not presented to the other groups. To compare the data for all five groups on the targets they had in common, the young adult data for the fifth target was omitted from consideration. The young adult group was tested first and when we realised how long each testing session was (more than 30 min), we reduced the number of targets to allow this test to fit the time allotted for the children and seniors.

Procedure

Participants were introduced to the task by first being shown each of the target objects from various angles, to increase their familiarity with them. They were not allowed to hold the targets. The instructions were to open the door to the room on each trial and then to find the target as quickly as possible. Participants were told that each of the targets would be presented in one of the cubicles of the shelf, always fully in view, but that the location and identity of each target would vary randomly from trial to trial.

Each trial began with the experimenter showing one of the targets to the participant, before going into the room and placing it on the shelves with the door closed. The experimenter referred to photographs of the target locations to ensure that targets were placed in the same location for each participant, in a randomized order. The experimenter then returned to the waiting room, letting the participant know that they could begin the trial when ready. Participants opened the door to the room, and stood on a location indicated by tape on the floor positioned 30 cm from the doorway. The full search configuration was visible to participants from this location. Timing of the search was based on the video record of each trial, with the time beginning when the door to the office opened and ending when the participants raised their arm to point at the target. Participants were tested in a single session that lasted about 30 min.

Results

Response Time and Accuracy

The dependent measure was the time that elapsed between the opening of the door to the room and the participant pointing correctly to the location of the target object. We refer to this as total response time and it was measured on each video, using the time that elapsed between the first frame of the videotape in which the door began to open and the first frame in which the participant's limb is in its final pointing position to the target. The total response time was further subdivided on each trial into the portion of time taken to open the door fully (door time), the time taken before the arm started to rise indicating the target location (search time), and the time taken to complete the pointing action (pointing time).

Participants did not make response errors in the technical sense, in that they found the target object on every trial. Examination of the reaction time (RT) distributions showed that 90% or more of all responses fell within a window of 2–20 s and that they were fairly typical RT distributions (normal with a slight positive skew). Yet, there were a sizable number of responses that fell outside these bounds and their number varied with age. We therefore took a 20-s cutoff in the RT distributions as a proxy for response errors and examined them with a between-participants analysis of variance (ANOVA) across the five groups. Note that using either more lenient or stricter cutoffs did not lead to results that differed in any respect from those we present here. The means of errors coded in this way are shown in Figure 2A and they indicate a U-shaped function over the life span. The main effect of group was significant, $F(4, 45) = 2.89$, $p < .04$, $\eta^2 = .20$. Simple effects indicated that both the youngest group and the aging faller group made significantly more errors than the college group ($p < .01$).

Figure 2B shows the total search time for each group, broken down by door time, search time, and pointing time. An ANOVA examined the between-participants factor of group and the repeated-measures factor of response component (door, search, point). The main effect of group was significant, $F(4, 45) = 4.36$, $p < .01$, $\eta^2 = .28$, reflecting the U-shaped function over the life span. The main effect of component was also significant, $F(2, 90) = 165.07$, $p < .001$, $\eta_p^2 = .79$, because the longest component of the total time was the time spent in search. The significant interaction of Group × Component, $F(8, 90) = 2.67$, $p < .01$, $\eta_p^2 = .19$, indicated that the U-shaped function was more pronounced for the search component than it was for the door and pointing components. Simple correlations among the three response components for each participant indicated that search time correlated most strongly with total response time, $r(48) = .992$, $p < .01$; less strongly with door time, $r(48) = .481$, $p < 01$; and least with pointing time, $r(48) = .181$, $p > .20$. Entering door time or pointing time as a covariate in the analyses of variance that we report in the following analyses, where search time is the dependent variable, did not alter any of the conclusions we report.

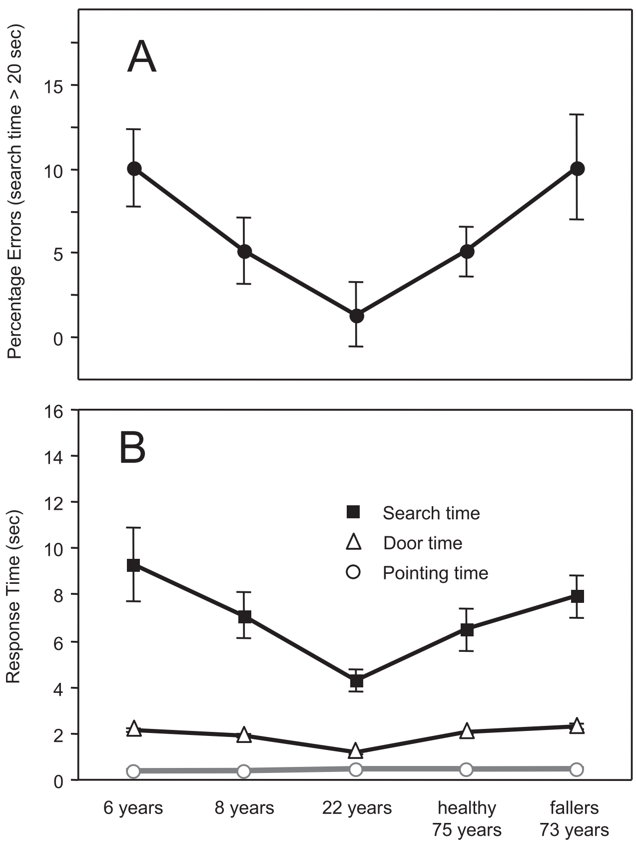

Figure 2. A: Mean errors in search (defined as total search time exceeding 20 s). B: Mean response time (s), broken down by door time, search time, and pointing time. Error bars represent +/− 1 *SEM*.

These results establish that response time and errors of everyday visual search across the life span are qualitatively similar to the results obtained in laboratory studies (Trick & Enns, 1998). Search becomes more efficient in time and accuracy as children develop into adults; this efficiency is more than a motoric slowing, as indicated by the larger effects of search time than of the more purely motoric effects of door opening and pointing; and efficiency of search declines with older age, especially in an aging population that is vulnerable to falls-risk. In the analyses that follow, we examine in greater detail some of the unique aspects of studying search with real-life objects in a large visual field. Because there were only 16 trials per participant, and these trials represented four target objects (apple, coffee can, golf ball, toy penguin), four visual search quadrants (upper left, upper right, lower right, lower left), and two eccentricities (center, peripheral), main effects and interactions with group could be examined for each of these factors, but interactions among target, quadrant, and eccentricity could not be examined systematically. To be clear, when examining any one of these factors across groups (e.g., target), each of the other factors were equally represented and uncorrelated (e.g., quadrant, eccentricity). However, interactions of target, quadrant, and eccentricity were not examined because not all cells were filled and because the remaining cells had only one observation per participant. We therefore performed separate analyses for the target objects (pooling over eccentricity and quadrants), eccentricity (pooling over targets and quadrants), and quadrants (pooling over targets and eccentricity). When significant main effects or interaction terms in the analyses were followed up with more detailed comparisons, the pooled error term was used for the follow-up tests.

We acknowledge that our subdivision of the overall search data to examine the factors of target object, eccentricity, and visual field is both exploratory and necessarily incomplete. In future research, the choice of target objects should be manipulated systematically, and sampled more broadly, to test a priori hypotheses about the role of biological relevance, familiarity, and personal relevance in visual search. To examine interactions among the factors, future studies will also have to collect considerably more data, either from each participant, or by testing a larger sample of participants. Moreover, the decision about how much data to collect to achieve adequate statistical power must be weighed against the costs and feasibility of collecting data from these special populations, who are both difficult to access and to keep engaged in repetitive tasks.

Target Object Salience Across the Life Span

One of the strongest age-related effects concerned the four different target objects that participants searched for. The mean search time for each of the targets is shown in Figure 3A. The data show that the apple was found relatively quickly and without many

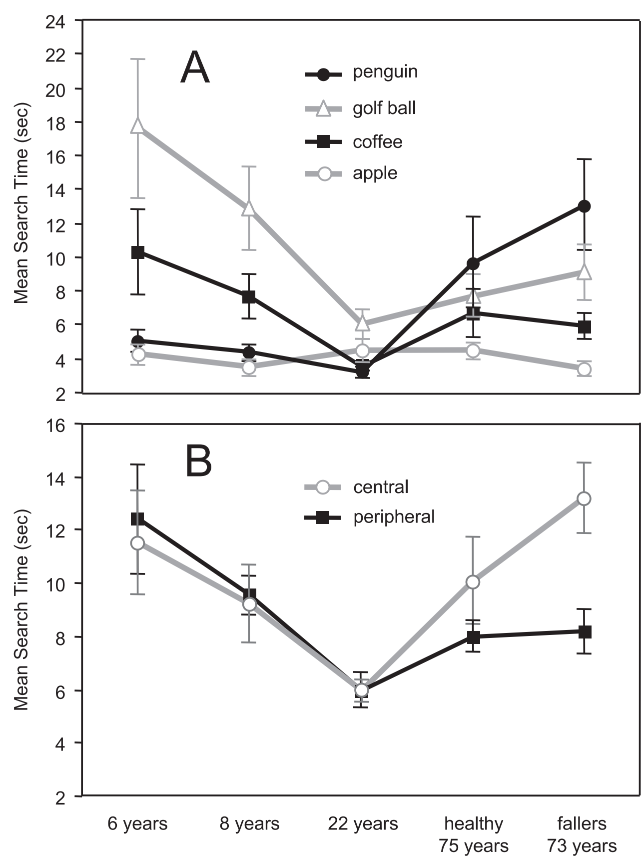

Figure 3. A: Mean search time (s) for each target. B: Mean search time (s) for central and peripheral targets. Error bars represent +/− 1 *SEM*.

differences by all participant groups. The golf ball and the coffee can both showed U-shaped functions over the life span, with the golf ball being generally more difficult to find than the coffee can. The one outlier object was the toy penguin, which was found with the equal efficiency by both groups of children and the young adults but was the most difficult object to find for the two groups of aging participants. These observations were supported by the following statistical analyses.

An ANOVA examined the between-participants factor of group and the repeated-measures factor of target (apple, coffee can, golf ball, toy penguin). In addition to the main effect of group, $F(4, 45) = 2.84$, $p < .04$, $\eta^2 = .20$, once again reflecting the U-shaped trend of search efficiency with age, there was a main effect of target, $F(3, 135) = 14.76$, $p < .001$, $\eta_p^2 = .25$, reflecting that the rank order of target difficulty was apple, coffee can, penguin and golf ball. However, this ordering varied with age, as indicated by a Group × Target interaction, $F(12, 135) = 3.96$, $p < .001$, $\eta_p^2 = .26$. This interaction was examined in closer detail by examining the group effect separately for each target. For apple, the group effect was not significant, $F(4, 45) < 1$, $\eta^2 = .03$. Nor was it for coffee can, $F(4, 45) = 2.17$, $p < .09$, $\eta^2 = .16$, though now there was a significant quadratic trend, $F(1, 45) = 5.36$, $p < .03$, which accounted for 62% of the variance in the group effect. However, there were significant group effects for the golf ball, $F(4, 45) = 3.30$, $p < .02$, $\eta^2 = .23$, where a significant linear trend, $F(1, 45) = 9.09$, $p < .01$, accounted for 69% of the variance in the group effect. For toy penguin, the group effect was also significant, $F(4, 45) = 7.92$, $p < .001$, $\eta^2 = .41$, though now a linear trend, $F(1, 45) = 22.21$, $p < .01$, accounting for 65% of the group variance, and a quadratic trend, $F(1, 45) = 8.40$, $p < .01$, accounting for 25% of the group variance, were each significant. Simple comparisons showed it was only the two aging groups that differed from the rest ($p < .05$).

We repeated these analyses with both log-transformed search times and with square root of arcsin search times as the transformation, to address the concern that the search time distributions tend to be positively skewed. Each of these transformations made the search time distributions closer to a normal distribution (logs gave a slight positive skew, arcsin gave a slight negative skew). In both cases the the F values we report here increased in size following these transformations, so we chose to report the more conservative analyses based most directly on the raw data.

Target Eccentricity Across the Life Span

The large-field visual environment in this experiment allowed us to see a dissociation between the age-related effects of central and peripheral targets. Figure 3B shows the mean search time for each of these two conditions. Whereas central and peripheral targets were similar in search difficulty for the two groups of children and young adults, peripheral targets were much easier to find than central targets for the two groups of aging participants. This observation was supported by the following statistical analyses.

An ANOVA examining group and eccentricity (central, peripheral) indicated a significant interaction between these factors, $F(4, 45) = 2.67$, $p < .04$, $\eta^2 = .19$. A separate examination of the central targets indicated the main effect of group was marginally significant, $F(4, 45) = 2.56$, $p < .06$, $\eta^2 = .19$, with a significant quadratic trend across the life span, $F(1, 45) = 8.59$, $p < .01$, accounting for 84% of the variance between groups. A similar analysis of the peripheral targets indicated a main effect of group, $F(4, 45) = 3.68$, $p < .02$, $\eta^2 = .25$, that included both a significant linear trend, $F(1, 45) = 8.80$, $p < .01$, (60% of the group variance) and a quadratic trend, $F(1, 45) = 4.77$, $p < .01$, (32% of the group variance). Pairwise difference tests between central and peripheral target locations indicated significant differences among the two aging groups combined, $F(4, 45) = 13.28$, $p < .01$, $\eta_p^2 = .41$, which when examined separately revealed a significant difference for the aging faller group, $F(4, 45) = 40.41$, $p < .01$, $\eta_p^2 = .82$, but not for the healthy aging group, $F(4, 45) = 1.49$, $p < .25$, $\eta_p^2 = .14$.

Visual Field Effects Across the Life Span

The results revealed some complex interactions of age and visual field that are summarised in Figures 4A and 4B. These should be treated with appropriate caution, since they represent the finest dissection of the data. When search efficiency was examined by organizing the four quadrants into two factors: left-right, and upper-lower there were significant two-way interactions for Group X Left-Right, $F(4, 45) = 9.81$, $p < .001$, $\eta_p^2 = .47$, and for Group × Upper-Lower, $F(4, 45) = 2.61$, $p < .05$, $\eta_p^2 = .19$. The three-way interaction of Group × Left-Right × Upper-Lower was not significant, $F(4, 45) = 1.51$, $p < .21$, $\eta_p^2 = .10$.

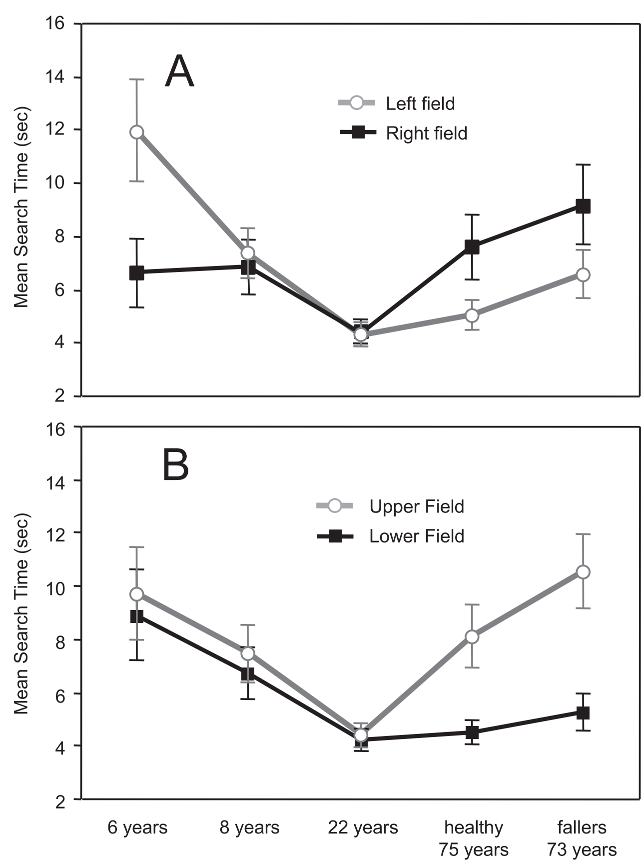

Figure 4. A: Mean search time (s) for left versus right targets. B: Mean search time (s) for upper versus lower targets. Error bars represent +/− 1 *SEM*.

The left-right effects (Figure 4A) pointed to left-field neglect (or slowing) for the youngest children ($p < .05$), and conversely, a right-field neglect (slowing) for the two older participant groups ($p < .05$). The older group of children and the young adults showed no left-right differences of any kind.

The upper-lower effects (Figure 4B) indicated that the youngest three groups of participants found targets equally easily in the upper and lower visual fields, but that the two groups of aging participants were especially disadvantaged when targets were presented in the upper visual field ($p < .05$).

Discussion

The goal of this study was to compare everyday visual search across the life span to address the five central questions we posed in the introduction. In this section, we return to each of these questions in turn, to consider how the data in this study addressed each one.

How Does Search in a Large Environment With Pointing Responses Compare to Previous Laboratory Studies?

The most consistent finding after several decades of study on visual search for coloured shapes on small computer screens is that there is a U-shaped pattern to the results over the life span (Hommel, Li, & Li, 2004; Plude et al., 1994; Trick & Enns, 1998). Visual search becomes more efficient, in both speed and accuracy, during childhood, and then decreases in efficiency during aging. Additional compromises to the aging process, as seen in the visual orienting and visual discrimination performance of individuals with early onset of dementia (Plude et al., 1994), and those at risk for dementia-like symptoms (i.e., participants with a history of falling, Nagamatsu et al., 2009), contribute further to the decrease in search efficiency that is associated with aging.

This study confirmed that the U-shaped pattern of search efficiency previously reported across the life span (Hommel, Li, & Li, 2004; Trick & Enns, 1998) applies to conditions that more closely approximate how people search for objects in everyday life. This was true despite a fourfold increase in the scale of measurement between the two types of study, such that an average increase in search time of 2 s in this study was approximately equal to a 500 ms increase in Trick and Enns (1998). Yet, beyond this change in scale, children and older adults were both slower than young adults to find real-life objects in a large scale environment. A 2-year age difference in childhood, from 6 to 8 years of age, was associated with a 2-s improvement in search efficiency. At the other end of the life span, healthy 74-year-olds searched at a similar speed to 8-year-olds, which was approximately 4 s slower than young adults.

Previous laboratory studies showing a U-shaped life span pattern have either proposed general hypotheses about the mechanisms that account for the increase in search efficiency during childhood and the decrease in aging, or more nuanced hypotheses proposing that different mechanisms are responsible for the U-shaped pattern at each end of the life span. Among the two most prominent proposals for global mechanisms are generalized neuronal slowing and a reduced ability to engage in perceptual inhibition. The slowing hypothesis proposes that child development is associated with exponential gains in information-processing speed at all levels of the brain (Kail, 1991), and that cognitive aging is related to the general slowing of these same information processing (Cerella, 1985; Salthouse, 1996). Reduced inhibition theories begin by assuming that most cognitive tasks require the efficient inhibition of irrelevant information in order to privilege the most important, task-relevant information. Improvements in cognitive function early in life are therefore attributed to the strengthening of inhibitory mechanisms (Dempster, 1992; Diamond, 1990; Harnishfeger, 1995), and cognitive aging is associated with the functional decline of efficient inhibition of task-irrelevant information (Hasher & Zacks, 1988; Tipper, 1991).

These global theories are of course, not mutually exclusive of each other. In the context of visual search, it is reasonable to assume that global slowing would result in less efficient visual search for both children and the elderly. The key idea separating this theory from the reduced inhibition hypothesis is that the slowing would apply equally to all aspects of cognitive functioning, even though its consequences might be felt disproportionately on tasks that are the most difficult for a participant to perform. The inhibition hypothesis is more specific with regard to visual search, since it predicts that the effects of development and aging would be most pronounced when attentional selection was required (i.e., when the similarity between target and distractor items was great and/or when the number of distractors was large).

In contrast to these global theories are studies that have asked whether the mechanisms implicated at each end of the life span might be different. For example, Trick and Enns (1998) broke down that task of visual search into a series of isolated mental constructs and concluded that the U-shaped pattern across the life span derives from different factors at each end of life. Specifically, they concluded that feature conjunction (i.e., binding visual features to a common object) posed problems for young children but not for elderly adults. In contrast, both children and seniors were less efficient than young adults when it came to moving spatial attention voluntarily from item to item. Hommel et al. (2004) came to a similar conclusion in studying visual search over the life span. Young children's search was particularly affected by the mere presence of distractors; whereas later in life, search was impaired by both increasing numbers of distractors and the decision to abandon search on target absent trials. Trick, Enns, and Brodeur (1996) reported that efficient visual counting of small amounts (enumerating quantities in the range 1–4) by healthy elderly participants equaled the ability of young adults, despite these same participants only being able to enumerate larger quantities at the reduced level of 10-year-olds. These are only three representative studies arguing for greater nuance in understanding of the U-shaped life span trend; maturation and senescence are not merely mirror images of one another.

The general theories face a new set of challenges in trying to accommodate the findings of the present study. A first pertinent finding is that the slower behavior seen at each end of life, which superficially might be seen as favoring the general theories, is not uniformly strong for all measures. A simple measure of the time needed to open the door to enter the room (door time), and another measure of the time used to raise a limb in response to finding a target (pointing time), did not reveal as strong a U-shaped pattern as the time needed to find the target once the search environment was visible. Admittedly, finding the targets in this large environment required its own subsets of motor action, because body, head, and eye movements were all involved in having a search come to a successful conclusion, as all of them did. However, the important point was that, to the extent generally slower motor actions were responsible for the developmental findings, the nonsearch motor actions did not show as strong a U-shaped pattern as the search-related motor actions did. This is consistent with the conclusion of Cerella et al., (1980) that the limiting factor in the slower searches of young and old participants is more mental (central nervous system) than it is motoric (sensory-motor).

What Does Search for Everyday Objects Contribute to Our Understanding?

A second finding that poses a serious challenge to global theories is the differential salience of some target objects. At one extreme was the apple target, which was found with similar speed by participants of all ages. At the other extreme was the toy penguin, which children found with efficiency equal to that of the young adults, but which the two elderly groups found most difficult.

These findings suggest that the personal relevance of the target object matters a great deal under everyday search conditions. Although it is possible the apple was found efficiently by participants of all ages because it contrasted most strongly with the background objects (Nagy & Cone, 1996), or because evolution has tuned human vision for ripe fruit colors (Bompas, Kendall, & Sumner, 2013), we think these explanations are unlikely. As shown in Figure 1, the apple was not especially unique in form or color from the nontarget objects. For example, the tomato distractor shares many of these features with the apple, as do other objects. A more likely explanation is that the apple was found efficiently at all ages because it is related to food, in the context of distractor items that are mostly not food. This means the apple may be salient because it is known by participants to satisfy a basic biological drive and has been previously associated with many rewarding appetitive experiences.

This is consistent with much other recent research showing that other objects of high evolutionary importance, such as threatening objects like guns (Fox, Griggs, & Mouchlianitis, 2007) and spiders (Kindt & Brosschot, 1999), and depictions of social stimuli such of adult faces (Langton, Law, Burton, & Schweinberger, 2008) and baby faces (Brosch, Sander, Pourtois, & Scherer, 2008) receive privileged attentional processing.

When the toy penguin target is considered in a similar way, it is likely that it was much more personally relevant to the children than it was to the older adults, simply because toys are a category of object designed for, used, and loved by children. This account based on personal relevance aligns well with electrophysiological evidence demonstrating attentional enhancement of self-relevant information (e.g., Berlad & Pratt, 1995; Tacikowski & Nowicka, 2010;) and self-owned objects (Sui, He, & Humphreys, 2012; Truong, Turk, & Handy, 2013; Turk, van Bussel, Brebner, at el., 2011).

These findings are difficult to reconcile with general theories appealing to neuronal slowing and reduced inhibition as the mechanisms underlying the developmental changes in visual search. These global mechanisms should have had a similar effect for a given participant group on all the targets. To accommodate these findings, global theories would have to allow for familiarity or personal relevance to have a moderating effect on the main mechanism (i.e., slowing or inhibition).

We think these results pose even more fundamental challenges for the traditional view that attentional selection precedes the assignment of value to stimuli that are being selected for more detailed processing (Posner, 1978; Treisman & Gelade, 1980). Instead, the finding of differential salience of the four targets across the life span is consistent with a more dynamic view, one in which the gate of attention is determined by a complex web of considerations that include the role of emotion, personal relevance, motivation, and reward history (Anderson, 2011; Awh, Belopolsky, & Theeuwes, 2012; Ristic & Enns, 2015; Krauzlis et al., 2014). In this way of thinking, attention is reframed as an outcome, that is, as a dependent variable, rather than as the independent variable that governs which perceptual information is privileged for detailed processing. As such, it makes little sense to try to study the life span trajectory of a general purpose mechanism of attention, when that mechanism is not fixed in any sense, but rather reflects the outcome of a complex dynamic interplay between a person's history, their environment, their immediate goals and their sensory system.

How Does Visual Clutter Influence Everyday Visual Search?

The literature on life span changes in visual search has been dominated by two theoretical constructs: the useful field of view and crowding. We will briefly summarise each of these proposed mechanisms, in considering how they might account for the consequences of visual clutter seen in the present study.

Several decades of research in the lab have supported the conclusion that the effective field of view in a single fixation grows in childhood and diminishes with aging. The term *useful field of view* was coined by Ball et al. (1988) to refer to this finding. Many others have since shown that childhood and aging are associated with a restricted useful field of view. For instance, detailed modelling of the aging effects in visual search suggests that older adults take smaller perceptual samples from a visual scene and scan these samples more slowly than do the young adults (Scialfa et al., 1987). The concept has also been broadened to include situations in which eye movements are made and here it is called visual span (Nuthmann, 2014, 2014).

A closely related phenomenon, but with a separate literature, concerns visual crowding. *Crowding* refers to the outcome that many visual functions (e.g., acuity, discrimination, identification) deteriorate when the target of the visual analysis is in close spatial proximity to other objects (Bouma, 1970). Children and older adults often demonstrate a disproportionate loss in measures such as perceptual span (Kail, 1991; Rayner, Castelhano, & Yang, 2009) and visual search (Enns & Girgus, 1985; Scialfa & Joffe, 1997) that have been interpreted as a consequence of crowding (Pelli et al., 2007; Scialfa et al., 2013).

These two concepts clash when considering the effects of clutter on life span search in an everyday setting (e.g., Henderson, Chanceaux, & Smith, 2009; Neider & Zelinsky, 2011). This is because a limited visual span should be expressed as a reduction in search success in the visual periphery, whereas an increased vulnerability to crowding should be expressed as reduced search success when identifying central targets, which are surrounded by a larger number of objects than peripheral targets. If we assume both factors may be at work, but to differing degrees in a given population, it becomes difficult to tease them apart. Some researchers, such as Sekuler, Bennett, and Mamelak (2000), have tried to resolve this clash in concepts by noting that the age-related deterioration of visual function is best conceptualized as a decrease in the efficiency with which observers can extract information from a cluttered scene, rather than of a shrinking of the field of view per se. They have supported this functional account by noting that the diminished efficiency of elderly observers is exacerbated when conditions require the division of attention between primary and secondary tasks. Others have tried to resolve the clash by studying the nature of peripheral visual representations in greater detail (Rosenholtz et al., 2012), arguing that those representations are based on summary statistics rather than object representations.

The present study gave us the opportunity to examine how the constructs of decreased visual span and increased visual crowding in childhood and old age play out in an everyday cluttered visual search. It is important to note that many previous laboratory studies of crowding and visual span generally involve small displays (i.e., small in the sense that all information is potentially available within a single glance) and that eye movements are not often required to perform the tasks. Indeed, eye movements are usually actively discouraged, to control for the fixation location on each trial. It is also important to note that age comparisons have typically been made piecemeal, either at the younger or the older end of the life span, but not at both ends with the same time procedure.

In contrast to these limitations, the present study provided an opportunity to study visual search in a situation where body, head, or eye movements were essential to being able to acquire all the relevant information to perform the search task. Although this mitigates the ability to attribute performance cleanly to either "central" or "peripheral" vision, as defined by retinotopic coordinates, it does allow us to distinguish between targets that are surrounded by many (i.e., central) versus fewer other objects (i.e., peripheral) in world-centered coordinates. As we have noted in previous studies of everyday visual search with healthy young adults (Brennan et al., 2011), the most efficient searchers tend to use body and head movements, even more than eye movements, to complete searches under these conditions.

The results here showed that under everyday search conditions, targets surrounded by relatively more clutter (central) and less clutter (peripheral) were found with quite similar efficiency in both children and young adults. This implies that some of the previous well-established labouratory findings of developmental expansion in the useful field of view may be attributable to the requirement not to make eye movements during the task. If children find that restriction more difficult than adults, then their reduced useful field of view may be consequence of that secondary task requirement, in the same way that dual tasks place greater stress on children (Guttentag, 1989) and on the elderly (Sekuler et al., 2000) than on young adults in many cognitive tasks.

The notable exception to the similar search times for central and peripheral targets was the search time for the two groups of older adults, who were slower to find central than peripheral targets. This means older participants were especially hindered when targets were cluttered. Our interpretation, in keeping with Sekuler et al. (2000), is that crowding is more of a limiting factor for everyday visual search than is the notion of a limited useful field of view. If the useful field of view was limited in older adults to a region near central vision, as suggested by Ball et al. (1988), then they would have been faster to find centrally than peripherally located targets. But indeed, the opposite results were found. Not finding these well-established laboratory effects in the context of everyday visual search helps to emphasize the importance of testing theories of age-changes in cognitive processes under conditions that more closely approximate their use in everyday life. For example, the present finding of a central target disadvantage in the elderly may have unexplored implications for driving and other everyday tasks were safety is of critical concern.

The finding of reduced search efficiency for centrally located object in the elderly, but not in children, poses a third challenge to global theories of slowing and reduced inhibition. This is because the less efficient search by children, relative to young adults, is dissociated by this finding from the less efficient search of older adults. Whereas centrally located targets led to a fairly symmetrical U-shaped pattern, peripherally located targets did not (Figure 3B). Clearly, different mechanisms need to be proposed for the different findings of peripherally located targets at opposite ends of the life span.

Are There Life Span Differences in Visual Field Effects in Everyday Visual Search?

This study also allowed us to explore differences across the life span in any biases to inspect one side of the visual field before the other. Reasons to expect such biases include (a) developmental and aging effects on hemisphere/visual field specialization, (b) the effects of environment and culture on strategies for exploration, and (c) bodily posture effects associated with development, aging, and task requirements (i.e., opening the door and entering a room to look for and find an object). The results surprised us in revealing age-related visual field effects were quite pronounced in how they differed across the life span.

First, there were differences in the speed of finding targets in the left and right visual fields. The youngest children showed a bias to find targets in the right visual field most quickly, older children and adults were quite evenhanded, whereas older adults showed the opposite bias to young children of finding targets most quickly in the left visual field. This is not a pattern that lends itself to a single-construct explanation by brain hemisphere specialization, cultural/environmental effects, or differences in the body postural approach to the task. However, the theorizing of Baltes and colleagues may hold a clue (Baltes, 1997; Baltes, Reese, & Lipsitt, 1980. This perspective, based on the idea that the primary source of developmental variation will change dynamically over the life span, proposes that early developmental differences are driven primarily by biological factors and cognitive mechanics, whereas performance differences later in life, while still reflecting those factors and mechanics, also reflect a strong reliance on a lifetime of experience and compensatory strategies for failing mechanics. In this view, the bias of young children to look right first rather than left may reflect an underdeveloped spatial attention brain network, which begins with a left-side bias because of its right-hemisphere home, but eventually settles into a similar allocation of attention to both the right and the left sides of space as its connections with other brain networks become more fully established (Kinsbourne, 1987). In North American culture, as literacy and other related cultural practices such as negotiating in traffic begin to take hold, this biological bias interacts with learned strategies that bias reading and exploring from left to right. For example, elderly participants seem to rely more on learned contextual factors in a visual search task (e.g., expect to find bread in a kitchen) than younger participants (Borges & Coco, 2015). If a similar thing is happening here, then older adults may be relying on the left-to-right scanning practices of their culture and applying them to the everyday search task, with the consequence that they favor targets in the left visual field. The older adults may have also been visually led by the path of the opening door, though it is then also not clear why this didn't affect the children in a similar way.

But it is also clear that there are many mixed results in the literature when it comes to left-versus right biases in visual scanning, and so deriving strong conclusions from a single study is not advised (Brooks, 2014; Christman, 1997). For example, studies by some of the current authors, testing healthy seniors and seniors with a history of falls from the same population that this sample was drawn from, conflicts with the present findings. Participants performed simple visual orienting and discrimination tasks on a small computer screen, with the requirement not to move the eyes because of associated ERP measurement. In this context, seniors with a history of falling showed left visual field deficits (Nagamatsu, Liu-Ambrose, Carolan, & Handy, 2009; Nagamatsu, Munkacsy, Liu-Ambrose, & Handy, 2013). Clearly, more systematic comparisons of the different factors involved in these experiments are needed.

A second visual field effect of note was the upper visual field deficit that was only observed in older adults, but not in children or young adults. Besides posing problems for the global theories of life span development, in the same way as the eccentricity effects that were specific to the two elderly groups, this finding could be caused by any number of factors. Among them is the possibility that postural changes (i.e., a more stooped posture) and/or attentional changes associated with aging (i.e., needing to look more closely where one is walking) are responsible for this effect. Again, more systematic tests of hypotheses such as these are now required.

Is Cognitive Vulnerability in Aging Evident in Everyday Visual Search?

Finally, this study showed that visual search efficiency does not only vary with age, but that search efficiency was greater for healthy seniors than seniors of a similar age with a history of falling. Falls in seniors are an important real-life consequence of visual-spatial attention impairments (Liu-Ambrose et al., 2008; Nagamatsu et al., 2009) that result in many injuries and injury-related deaths associated with aging. The present findings are yet another illustration that the attention impairments of fallers are demonstrable in a brief task that closely resembles how attention is used in everyday life. In this context, it is important to be reminded that the difference in everyday search efficiency reported in this study was not the result of any generalised cognitive deficits, since the Mini Mental State Examination score for all senior participants was a respectable 24 or higher. Neither do the results suggest that our observed differences in search efficiency reflected general motor deficits, because both healthy and falling seniors differed in their search time, but not their door opening or pointing speeds.

In conclusion, we offer the findings presented here and their surrounding discussion to demonstrate the importance of studying cognitive processes and behavior under conditions that approximate those of everyday life. Under these conditions, factors such as personal relevance, life history, and body movement capabilities have an opportunity to reveal their influence on visual-spatial attention. We hope this article encourages future research on cognition and behavior in the everyday settings in which they occur.

Résumé

Cette étude visait à comparer la recherche visuelle dans des conditions de tous les jours chez des participants pendant toute la durée de vie (4 groupes de participants en santé d'âge moyen respectif de 6 ans, 8 ans, 22 ans et 75 ans et 1 groupe composé de personnes d'âge moyen de 73 ans ayant été victimes de chute). La tâche consistait à ouvrir une porte et à pénétrer dans une pièce afin d'y trouver un parmi quatre objets de tous les jours (une pomme, une balle de golf, une boîte de conserve de café, un jouet pingouin) bien en évidence, sur des tablettes. Cette étude s'appuie sur deux études de laboratoire bien citées soulignant différents mécanismes cognitifs qui sous-tendent chaque extrémité du schéma en forme de U de la recherche visuelle pendant toute la durée de vie (Hommel et al., 2004; Trick & Enns, 1998). Les résultats reprenaient certains des principaux résultats de l'étude de laboratoire (par ex. une fonction en forme de U, des facteurs dissociables de la maturation et du vieillissement), mais on y a tout de même fait plusieurs constats uniques. Ces derniers comprenaient de grandes différences au niveau de l'importance de la ligne de base d'objets courants à des âges variés, des effets d'excentricité visuelle, qui sont caractéristiques de l'âge, et des effets de champs visuels qui interagissaient fortement avec l'âge. Ces constats soulignent l'importance d'étudier les processus cognitifs dans des contextes plus naturels, où des facteurs tels la pertinence sur le plan personnel, l'expérience de vie et les contributions corporelles à la cognition (par ex., les mouvements des jambes, de la tête et du corps) et sont plus aisément dévoilés.

Mots-clés : durée de vie, attention, recherche visuelle, enfants, personnes victimes de chutes.

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