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Hybrid Foraging Search in Younger and Older Age

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In hybrid foraging tasks, observers search visual displays, so called patches, for multiple instances of any of several types of targets with the goal of collecting targets as quickly as possible. Here, targets were photorealistic objects. Younger and older adults collected targets by mouse clicks. They could move to the next patch whenever they decided to do so. The number of targets held in memory varied between 8 and 64 objects, and the number of items (targets and distractors) in the patches varied between 60 and 105 objects. Older adults foraged somewhat less efficiently than younger adults due to a more exploitative search strategy. When target items became depleted in a patch and search slowed down, younger adults acted according to the optimal foraging theory and moved on to the next patch when the instantaneous rate of collection was close to their average rate of collection. Older adults, by contrast, were more likely to stay longer and spend time searching for the last few targets. Within a patch, both younger and older adults tended to collect the same type of target in "runs." This behavior is more efficient than continual switching between target types. Furthermore, after correction for general age-related slowing, RT × set size functions revealed largely preserved attention and memory functions in older age. Hybrid foraging tasks share features with important real-world search tasks. Differences between younger and older observers on this task may therefore help to explain age differences in many complex search tasks of daily life.

Keywords: cognitive aging, optimal foraging, visual attention, memory, strategies

Supplemental materials: http://dx.doi.org/10.1037/pag0000387.supp

Searching in the visual world is a ubiquitous task of daily life: We look for products in the grocery store, our friends in a crowd of people, tablets in the medicine cabinet, or news on web pages. Older adults experience difficulties in a variety of real-world visual tasks, and there are multiple cognitive processes that potentially contribute to less efficient search behavior in older age (Stanovich, 2011). One assumed source is age-related decline in attentional control (e.g., McDowd & Shaw, 2000). In visual search, attentional control is involved in the top-down selection of task-relevant information that is difficult to distinguish from surrounding distracting information, as in a cluttered display or scene (Grahame, Laberge, & Scialfa, 2004; Ho, Scialfa, Caird, & Graw, 2001; Madden, 2007). Another key function assumed to be affected by aging is episodic long-term memory, the explicit retrieval of events from the past (Grady & Craik, 2000; Naveh-Benjamin, 2000). Visual representations retrieved from long-term memory enable observers to find and recognize previously encountered objects, faces, and scenes. Besides these cognitive limitations, age-related changes in strategies, goals, and beliefs (Mather, 2006) influence how older observers gather information in the visual world. Previous research suggests that older adults, compared to younger adults, favor exploitative over explorative behavior (Chin, Anderson, Chin, & Fu, 2015; Chin, Fu, & Kannampallil, 2009; Chin, Payne, Fu, Morrow, & Stine-Morrow, 2015). However, aging can be associated with a decrease in exploitation in difficult search tasks. It is assumed that this reduced exploration under high cognitive load is adaptive to a domain-

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general age-related impairment in cognitive control processes (Hills, Mata, Wilke, & Samanez-Larkin, 2013; Liu et al., 2016; Mata & von Helversen, 2015).

In the present study, we investigate how age differences in attention, memory, and search strategy affect performance in a "hybrid foraging task" (Á. Kristjánsson, Jóhannesson, & Thornton, 2014; Wolfe, Aizenman, Boettcher, & Cain, 2016). In classic visual search, observers search for an instance of one type of target. In "hybrid search," observers search for an instance of any of several target types, held in memory. Thus, hybrid search combines visual and memory searches. In classic foraging tasks, observers collect multiple instances of a single target type from visual displays. "Hybrid foraging," the task used here, combines hybrid search with foraging: Observers are looking for multiple instances of multiple target types. A real-world example of a hybrid foraging task would be helping your grandchild to find all crayons, pads of paper, and stuffed bears that need to be taken on vacation. In the laboratory version of this task introduced by Wolfe and colleagues (2016), young adult observers first memorized 8 to 64 realistic photo objects and then searched for multiple instances of any of the target objects they held in memory through several displays, so called "patches."[1] See Figure 1 for an example of a patch, in which observers might be collecting motorcycle helmets, baseball caps, and backpacks.

Observers gained points for each correctly collected target and were instructed to achieve a given number of total points as quickly and as accurate as possible. Over time, the targets in the current patch become depleted, and thus search becomes harder. The total number of targets in a patch was unknown. Importantly, observers were free to choose when to leave the current patch to "travel" to the next patch, that is, observers were not instructed to search exhaustively. In such a foraging task, it is important to know when the observer decides to leave the patch to travel to the next. This would not be an issue under exhaustive search conditions, where the observer is required to collect all targets (Á. Kristjánsson et al., 2014). In the younger sample investigated by Wolfe and colleagues (2016), the average time when observers decided to move to the next patch largely followed predictions based on Charnov's Marginal Value Theorem (MVT). MVT is an optimal foraging model that was originally studied in the animal literature (Pyke, 1978). MVT states that the optimal forager in a nonexhaustive search scenario will travel to a new patch when the instantaneous rate of collection from the current patch drops below the average rate of collection over all patches (Charnov, 1976). The effects of attention and memory load on hybrid foraging performance can be seen in RT × set size functions. In young adult observers, mean response time (RT), across patches, was shown to increase linearly with the number of items in the visual display and logarithmically with the number of items in the memory set (Wolfe et al., 2016). This is similar to the RT results reported in simple hybrid search tasks, where observers search for just one instance of any of several possible targets among distractors (Boettcher & Wolfe, 2015; Cunningham & Wolfe, 2014; Wolfe, 2012; Wolfe, Boettcher, Josephs, Cunningham, & Drew, 2015). In addition, it is possible to analyze how the observer organizes search within a patch in hybrid foraging. Younger observers typically do not pick randomly among available targets; rather, they collect items in "runs" of picking instances of the same target type (Wolfe et al., 2016). In the example (see Figure 1), this might mean that an observer would collect helmets, one after another, until the rate for helmet collection drops to some level. At that point, the observer might switch to backpacks, and so forth. Notably, the same tendency to search in runs is found in foraging tasks with multiple targets using simple, abstract stimulus material like colored simple shapes (Á. Kristjánsson et al., 2014; Wolfe et al., 2019). The RT data indicate that searching again for the same item is faster than switching to search for another target type. This behavior can be seen as the product of two forms of priming (Á. Kristjánsson, & Campana, 2010; or selection history effects; Awh, Belopolsky, & Theeuwes, 2012; Theeuwes, 2018). First, selection of one item primes the fundamental features of that item (color, size, etc.). This makes it more likely that attention will be guided to a subsequent item with those features. Second, selection of one item primes the identity/meaning of that item (Neely, 1977; Posner & Snyder, 1975; Sperber, McCauley, Ragain, & Weil, 1979). This makes it faster to identify a subsequent target if it has the same, primed identity. At the same time, searching for and identifying a new target type takes longer, imposing a type of switch cost (Monsell, 2003; Wolfe, Cain, & Aizenman, 2019). Previous studies demonstrated that feature- and identity-repetition priming effects are largely spared in older age (Fleischman & Gabrieli, 1998; Laver & Burke, 1993; Madden, 2007; McCarley, Kramer, Colcombe, & Scialfa, 2004; Wiegand, Finke, Müller, & Töllner, 2013). By contrast, switch behavior may change with age. Task-switching paradigms showed increased switch costs in older age largely consistently (Craik & Bialystok, 2006; Kramer, Hahn, & Gopher, 1999). However, in a semantic fluency information search task, older adults were less perseverant and tended to switch more between retrieval cues (Hills et al., 2013). Whether and how switch costs between target types vary with age in the hybrid foraging task remains to be tested.

In the present study, we examine whether and how performance differs between younger and older observers in a hybrid foraging task, similar to the one introduced by Wolfe et al. (2016). One may expect that age-related decline in attention and memory results in higher RT costs for older adults as visual and memory set sizes increase. However, our previous results from single-target hybrid search did not reveal age-specific impairments beyond general age-related slowing (Wiegand & Wolfe, 2019), and our present data replicate that finding. Apart from changing RT × set size functions, memory decline may cause older observers to omit certain target types entirely because they dropped from their memory. Our results do not support this either. Second, previous work using tasks like virtual fishing (Mata, Wilke, & Czienskowski, 2009, 2013), digital information search (Chin, Anderson, et al., 2015), or word search puzzles (Chin, Payne, et al., 2015) showed that older adults adopt a more exploitative foraging strategy than younger observers. Thus, in the hybrid foraging task, older observers might leave patches later than would be predicted by MVT. As we will show, on average, older observers indeed do wait until the instantaneous rate of collection has dropped significantly below the average rate of collection before leaving the patch. This makes them less efficient than younger adults in terms of points

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[1] Individual screenfuls of items are referred to as "patches" because the foraging literature has its roots in studies of animal foraging from one patch of food to another.

Figure 1. Illustration of an example display for a memory set size of 8 objects and an initial visual set size of 60 objects. The current score and the next button are presented in the middle of the screen. See the online article for the color version of this figure.

per unit of time. Finally, we suspected older observers may stick longer in runs within a patch and avoid costly switches between target types because their flexibility in activating target templates from long-term memory is reduced. However, younger and older observers showed very similar within-patch search strategies and comparable switch costs.

Method

Participants

We collected the data from 12 healthy younger adults (Mean age = 24.18, *SD* = 2.68, 11 female) and 12 older adults (Mean age = 72.50, *SD* = 5.35, 6 female). All participants had to meet the inclusion criteria and pass the screening process described below. The participants were recruited by a clinical trials announcement of Partners/Brigham and Women's hospital, Boston University (only younger adults), and advertisement in the magazine *FiftyPlus Advocate* (only older adults). Data were collected in accordance with the Declaration of Helsinki on ethical principles. Participants took part voluntarily, gave their informed consent, and were paid $11 per hour for their time. The Partners Health Care Corporation Institutional Review Board approved all experimental procedures.

Participants had at least 20/25 visual acuity (including correction through glasses) and passed the Ishihara test for colorblindness. Moreover, participants could not take part in the experiment if they reported any history of any eye or muscular disorder, somatic disorder, neurological disorder or psychological/psychiatric disorder. We further screened participants for present severe depressive symptoms using the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977), and older participants for signs of beginning dementia using the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). Participants who had scores higher than 20 on the CES-D or scores below 26 on the MMSE could not take part in the upcoming experiment. One older participant had to be excluded from the experiment due to this reason.

Of those who were eligible, we further assessed demographic information (age, sex, education) using a questionnaire, verbal abilities (verbal IQ) by the North American Adult Reading Test (Blair & Spreen, 1989; Nelson, 1982), and cognitive and visuomotor speed by the digit symbol substitution task (Wechsler, 1958). Additionally, we assessed participants' subjective cognitive failures in everyday tasks by the Cognitive Failures Questionnaire Broadbent, Cooper, Fitzgerald, & Parkes, 1982) and older participants' cognitive reserve[2] by the Cognitive Reserve Index Questionnaire (Nucci, Mapelli, & Mondini, 2012). A comparison of the demographic information of our sample, including the data of the screening tests, can be found in Table 1. More details about the sample can be found in the online supplemental materials.

Stimulus Material and Apparatus

The stimulus items were drawn from 1,922 distinct, highly discriminable object images selected from the database of 2,400 unique objects developed by Brady, Konkle, Alvarez, and Oliva (2008). From the original folder, 474 images were removed for various reasons. We excluded objects that were primarily white or translucent and thus not very distinct from the background and objects that were cut off and, thus, might look odd in a moving display. In addition, we excluded images of objects that included words, numbers, or arrows or were very similar to other objects, images that showed landscapes or humans, images that contained multiple objects, and images that seemed potentially disturbing.

The stimuli were presented on a 24-in. screen with a refresh rate of 60 Hz, on an iMac, model A1225 (EMC 2211). The experiment was programmed in Matlab Version 9. 0.0 using the Psychtoolbox, Version 3.0.11 (Brainard, 1997). Items were up to 75 × 75 pixels, subtending a maximum of approximately 1.8 × 1.8 degrees of

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[2] Cognitive reserve refers to an individual's resilience to brain damage (Stern, 2002). It describes the phenomenon where older adults with more cognitively stimulating environments (e.g. longer education, challenging occupation, leisure and social activities) show less age-related cognitive decline.

Table 1
Demographic Information and Screening Test Results

Group	Age (years)	Sex (F/M)	Education (years)	Depressive symptoms (CES-D)	Vocabulary (NAART)	Cognitive-motor speed (DSST)
Younger adults	24.18 (2.68)	11/1	16.73 (1.49)	4.73 (4.80)	16 (4.69)	68 (7.99)
Older adults	72.50 (5.35)	6/6	16.58 (1.98)	5.17 (5.59)	10.00 (7.51)	49.25 (8.34)
	$t(20) = 26.977$	$\text{Chi}^2 = 4.196$	$t(20) = .198$	$t(20) = .409$	$t(16) = 1.661$	$t(20) = 18.750$
	$p < .001$	$p = .123$	$p = .847$	$p = .687$	$p = .116$	$p < .001$

Note. CES-D = Center for Epidemiologic Studies Depression Scale; DSST = Digit Symbol Substitution Test; NAART = North American Adult Reading Test; F = female; M = male. One younger adult did not complete the screening. Only 6 out of 12 younger adults completed the NAART, because the remaining participants were not native English speakers. Mean values and standard errors of the means (in parentheses) for younger adults and older adults and statistical tests of the age group comparisons.

visual angle at average viewing distance of 61 cm. The mouse curser had a size of 0.94 × 0.94 degrees of visual angle.

Experimental Procedure

The experiment had four blocks, each with a different memory set size of 8, 16, 32, or 64. The order of the blocks was randomly selected. Each block began with a memorization phase in which the target objects were presented individually on a white screen for three seconds, followed by an old/new recognition task (50% target prevalence) to test the observer's memory for the target set. If an observer failed to reach a level of 75% correct responses, the image stream and memorization test would be repeated. However, all younger and older observers achieved the criterion of 75% at the first attempt. Overall recognition rate was 94.76% for younger observers (SD = 4.02) and 94.92% for older observers (SD = 4.38) and did not differ between age groups ($T(22) = 0.095$, $p = .925$). Good recognition memory is a prerequisite to performance of the hybrid foraging task. Preserved recognition memory in older adults was reported earlier (Jennings & Jacoby, 1993; Yonelinas, 2002). The main question of the present experiment was to test whether the reactivation of the target templates from long-term memory during search differs between age groups.

After the recognition memory test was passed, the observer moved on to the hybrid foraging task, in which multiple instances of several of the memorized objects were to be found (via mouse click) in displays (or "patches," to use the foraging term) of moving objects. Stimuli moved continuously at a rate of 1.25°/s using an algorithm borrowed from multiple-object tracking experiments. Items independently moved toward randomly selected goal locations that changed over time. Items were repulsed by the edges of the patch, the center of the patch, and other items, although items could overlap. The objects in a patch consisted of memorized objects and novel distractor objects, which together constituted the visual set size of a patch. The initial visual set size varied among 60, 75, 90, and 105 objects and was selected randomly for each patch. When the observer clicked on an item, it disappeared from the patch. At the onset of each patch, 20%–30% of the objects in one patch were target objects. Regardless of the memory set size, two, three, four or five different target types were present in each patch, with the number of target types being randomly selected. The target types within a patch had similar counts. The number of distractor items was chosen such that target and distractor item types had similar counts. Across patches, target types and distractor types were chosen randomly and appeared equally often, within and across participants. Items that were targets in one block never appeared as distractors in another block. Distractors were never repeated within a block, but could reappear in another block, as there were not enough objects to use each item only once. Importantly, the number of repetitions of target and distractor items were the same for all participants, and thus for age groups. The random selections of visual set size across trials and memory set size across blocks were counterbalanced.

The task was to collect a given number of points as quickly as possible. In each experimental block, participants had to collect 1,000 points. For each collected target object, participants received 2 points and for each distractor they clicked on by mistake (false alarm), they lost 1 point. Participants received feedback about false alarms immediately in form of a red cross that appeared at the location of the collected distractor in order to prevent observers from continuing to collect a type of distractor item that had been erroneously classified as a target. Note that false alarms were very rare in both age groups (see "Basic Foraging Behavior: When Do Observers Move on to the Next Patch?" below). The current score was always presented in the middle of the search patch. Importantly, participants had to decide when they wanted to move to a new patch. They did not need to collect every target in a patch before moving and, in fact, were encouraged in the initial instructions to think about moving if they thought it would speed the collection of points (see online supplemental materials for the original instructions). To move to the next patch, participants clicked the "next" button in the middle of the patch. A 2-s "travel time" was added between patches. Because of the time required to compute the stimuli and other programming overhead, the total time from the last item collected in a patch to the appearance of the next patch was on average 5 s.

Before the experiment started, participants completed one shorter practice block with a memory set size of 16. The practice block was included to make sure that participants understood the instructions and to familiarize them with the task. The practice block was longer for older than younger participants. Older observers had to collect 100 points while younger observers collected only 50 points. As most older adults are less experienced with computers and skill learning takes longer than at younger ages (Broady, Chan, & Caputi, 2010), we were concerned that our older participants would not be sufficiently familiar with the task after collecting just 50 points, and we wanted to avoid substantial practice-related learning effects during the experiment. In the practice block, participants received feedback about the number of target objects they left behind (miss rates).

After the experiment, participants filled out a postexperiment questionnaire (see online supplemental materials), answering five questions about their search strategies and their strategies to memorize the different target object sets.

Statistical Analyses

Several independent variables were of interest in acquiring a comprehensive picture of age differences in hybrid foraging performance. We used ANOVAs, independent sample T tests, and paired T tests, with a significance level of $\alpha < .05$, to analyze miss rates, instantaneous and average target collection rates, and RT as a function of visual and memory set size, and age. For the RT × set size functions (see “RT × set Size Functions and General Slowing” below), we performed statistical analyses on raw RT and z-transformed RT (zRT). Specifically, we transformed the data for each individual by subtracting the mean RT from each click’s RT and dividing the difference by the standard deviation. The resulting standardized z-values allow comparing the relative condition differences between individuals independent of individual differences in mean raw RT, including overall age-related slowing (Faust, Balota, Spieler, & Ferraro, 1999). Notably, zRT should be used with caution when the relationship between the means and standard deviations of RT distributions varies across groups. This could result in the two groups’ zRT being unequally biased by the z transformation (cf. Faust et al., 1999). However, in our sample, the relationship between means and standard deviations was similar in the two age groups (mean/standard deviation younger: 1.11, mean/standard deviation older: 1.01; for RT distributions, see the online supplemental materials). Therefore, we were not concerned that age group differences have been artificially removed by the z transformation.

For all analyses, we report F, T, and p values together with effect sizes and confidence intervals (CI) for effect sizes. Given the rather small sample size and usual difficulties with null effects, we were concerned that we may have been underpowered to detect significant evidence for effects of age. Therefore, we also ran Bayesian statistics using JASP (http://www.jasp-stats.org; Rouder, Morey, Speckman, & Province, 2012; Rouder, Morey, Verhagen, Swagman, & Wagenmakers, 2017; Wagenmakers et al., [2018]). The analysis grades the evidence for two competing statistical models based on the data. The Bayes factor (BF) provides an estimate of how strongly the data support the presence of a hypothesized effect (BF10), but also how strongly a null effect is supported (BF01).

Results and Discussion

Basic Foraging Behavior: When Do Observers Move on to the Next Patch?

Overall, the number of viewed patches and clicks was comparable between age groups. On average, younger observers viewed 31.31 patches and clicked on 16.52 items in each patch. Older observers viewed 30.05 patches and clicked on 17.31 items in each patch. As foraging progresses in a patch, target prevalence decreases and targets become harder and harder to find. To maintain a high average rate of collection over a block, MVT predicts that the observer should leave a certain proportion of targets in a patch behind when moving on to the next one rather than search exhaustively for all targets. These uncollected items should not be considered as errors in a foraging task. Unless observers are asked to collect all items, these are strategic omissions. Nevertheless, we will refer to the “miss rate” when talking about the numbers of items left behind. We tested whether miss rates of targets varied with Visual Set Size (60, 75, 90, 105), Memory Set Size (4, 8, 16, 64), and Age (younger, older).

As Figure 2 shows, numerically, younger observers left more targets behind than older observers. However, an ANOVA did not yield a significant main effect of Age [$F(22, 1) = 0.964$, $p = .337$, $\eta^2 = 0.042$ (90% CI 0.000, 0.224)]. The BF indicated equivocal evidence for the effect of Age [BF10 = 0.548]. Replicating the earlier findings of Wolfe et al. (2016), miss rates increased with the number of targets in memory and decreased with the (initial) number of items in the patch, evidenced by main effects of Memory Set Size [$F(66, 3) = 16.827$, $p < .001$, $\eta^2 = 0.433$ (90% CI 0.261, 0.530)] and Visual Set Size [$F(66, 3) = 3.106$, $p = .032$, $\eta^2 = 0.124$ (90% CI 0.006, 0.222)]. BFs, however, did only suggest strong evidence for the presence of the Visual Set Size effect [BF10 = $3.800e^{17}$], but evidence for the absence of the Memory Set Size effect [BF01 = 22.394]. In addition, the three-

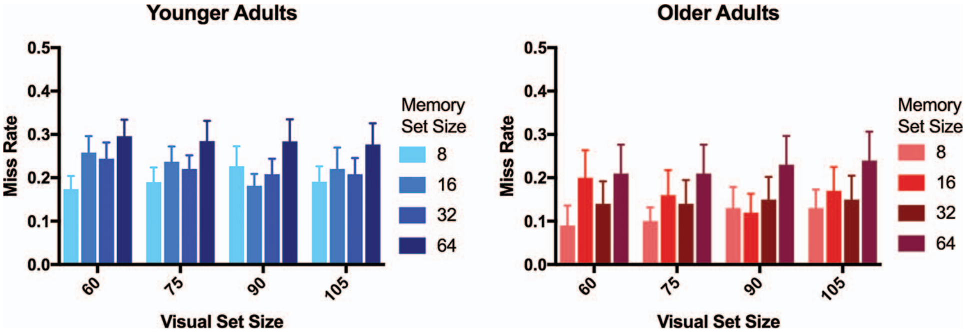

Figure 2. Average miss rates (proportions of total targets left uncollected) as a function of memory set size and visual set size for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

way interaction between Visual Set Size, Memory Set Size, and Age was significant [$F(198, 9) = 1.960$, $p = .046$, $\eta^2 = 0.082$ (90% CI 0.001, 0.107)]. None of the two-way interactions were significant [all $F < 1.6$, all $p > .10$]. BFs indicated evidence for an Age × Visual Set Size interaction [BF10 = 4.517], while the absence of other interactions was more likely [all BF01 > 1.738]. Follow-up ANOVAs revealed evidence for main effects of Memory Set Size in both age groups [younger: $F(33, 3) = 46.465$, $p < .001$, $\eta^2 = 0.809$ (90% CI 0.674, 0.852); BF10 = 2955.340; older: $F(33, 3) = 4.800$, $p = .007$, $\eta^2 = 0.304$ (90% CI 0.058, 0.438); BF10 = 5.370]. Post hoc contrasts showed that observers missed fewer targets in blocks with the smallest memory set size of 8 than in blocks with higher memory load [all $T > 3.07$, all $p < .005$, all $d > 0.40$ (95% CI 0.126, 0.700); all BF10 > 8.187] and missed more targets in blocks with the largest memory set size of 64 than in blocks with smaller memory load [all $T > 2.50$, all $p < .02$, all $d > 0.411$ (95% CI 0.066, 0.777); all BF10 > 2.736]. Only younger observers further showed a trend significant main effect of Visual Set Size for which Bayesian evidence was scarce [younger: $F(33, 3) = 4.773$, $p = .051$, $\eta^2 = 0.303$ (90% CI 0.057, 0.438); BF10 = 1.261; older: $F(33, 3) = 0.742$, $p = .535$, $\eta^2 = 0.063$ (90% CI 0.000, 0.158); BF01 = 7.336].

As noted above, uncollected items in a foraging task should not be regarded as false negative errors. However, it is possible that observers missed some targets because they slipped from the target set in memory. Especially when memory load is high, one of the many target items is more likely to be completely forgotten in a patch. Presumably, those types of misses may increase as a consequence of age-related memory decline (Grady & Craik, 2000).

This was not the case. Again, numerically, younger observers missed all instances of a target type more often than older observers (see Figure 3), although the main effect of Age in the ANOVA did not reach significance [$F(22, 1) = 2.498$, $p = .128$, $\eta^2 = .102$ (90% CI .000, .306)]. The BF indicated the effect of Age was equivocal (BF10 = 0.767). An effect of Memory Set Size [$F(66, 3) = 16.752$, $p < .001$, $\eta^2 = .432$ (90% CI .260, .530); BF10 = $7.745e^{15}$] indicated that the number of entirely missed target types rose with the number of targets in memory. Post hoc tests showed that observers missed fewer target types in blocks with the smallest memory set size of 8 than in blocks with higher memory load [all $T > 2.260$, all $p < .034$, all $d > 0.460$ (95% CI 0.036, 0.879); all BF10 > 1.802] and missed more targets in blocks with the largest memory set size of 64 than in blocks with smaller memory load [all $T > 3.016$, all $p < .007$, all $d > 0.616$ (95% CI 0.173, 1.047); all BF10 > 7.295]. There was a further interaction between Age and Memory Set Size [$F(66, 3) = 2.890$, $p = .042$, $\eta^2 = .116$ (90% CI .002, .213); BF10 = 33.470]. Older observers missed fewer target types than younger observers at memory set size 32 [$T(22) = 3.193$, $p = .004$, $d = 1.304$ (90% CI 0.405, 2.179); BF10 = 9.896], while the age groups did not differ for any other set size [all $T < 1.261$, all $p > .220$, all $d < 0.510$ [95% CI −0.305, 1.324]; all BF01 > 1.513]. The main effect of Visual Set Size was only trend significant [$F(66, 3) = 2.510$, $p = .066$, $\eta^2 = .102$ (90% CI .000, .196)], and the BF indicated more evidence for the absence of the effect [BF01 = 13.401].

Participants rarely clicked erroneously on distractor objects. Figure 4 shows the false alarm rates (number of false alarms/all objects clicked in patch), which were low for the younger sample (1.8%) and older sample (2.5%) and did not differ between age groups [$F(22, 1) = 0.574$, $p = .457$, $\eta^2 = .025$ (90% CI 0.000, 0.193); BF01 = 2.427]. There was no effect of Memory Set Size [$F(66, 3) = 1.350$, $p = .266$, $\eta^2 = .058$ (90% CI .000, .133); BF01 = 41.128], but an effect of Visual Set Size [$F(66, 3) = 12.572$, $p < .001$., $\eta^2 = .364$ (90% CI .190, .468); BF10 = $1.535e^{18}$]. False alarms increased with increasing display size. Post hoc *T* tests confirmed differences between all Visual Set Size conditions [all $T > 2.090$, $p < .05$, $d > 0.426$ (95% CI 0.004, 0.841); all BF10 > 1.350]. There were no two- and three-way interactions among Age, Visual Set Size, and Memory Set Size [all $F(66, 3) < 1.0$, $p > .50$, $\eta^2 < .04$. (90% CI 0.000, 0.110); all BF01 > 29.876].

The results for misses and false alarms do not suggest that a memory deficit, that is, higher forgetting rates or confusion of targets and distractors, affected older observers' task performance. In fact, younger observers completely omitted target types somewhat more often, suggesting a strategic age difference that is also found in other tasks: Older adults tend to put more emphasis on accuracy than younger adults, often at the expense of speed (G. A. Smith & Brewer, 1995). Depending on the task, this can lead to suboptimal performance levels. For example, in two-choice decision tasks, the decision boundaries adopted by older adults are farther away from the optimal speed–accuracy tradeoff than those of younger adults (Starns & Ratcliff, 2010, 2012). In the nonexhaustive hybrid foraging task particularly, trying to find more of

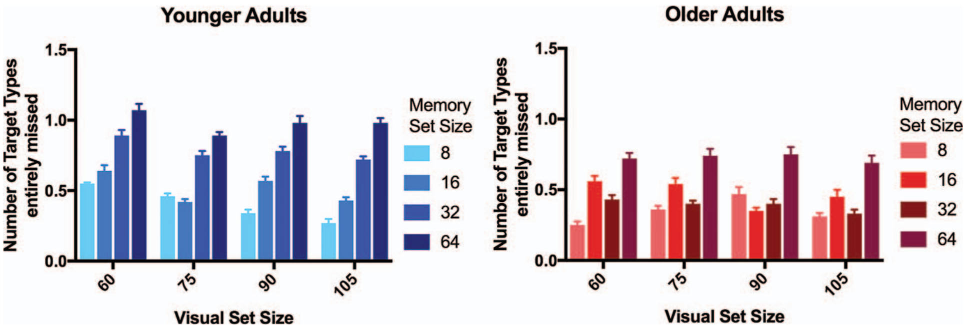

Figure 3. Average number of target types left entirely uncollected, as a function of memory set size and visual set size for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

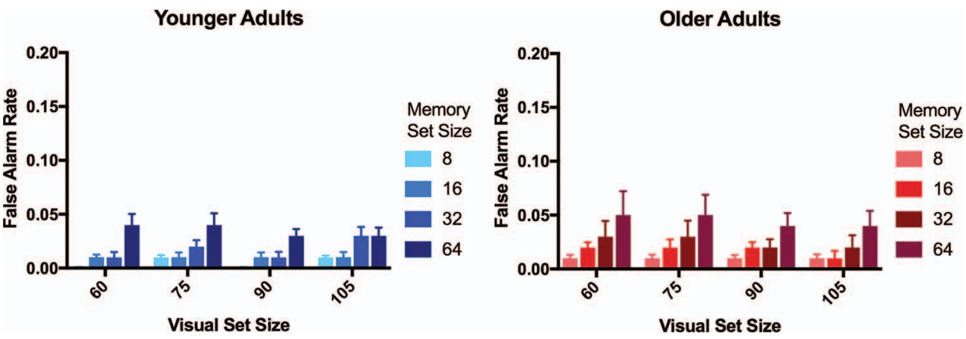

Figure 4. False alarm rates (clicks on distractors/all clicks in patch), as a function of memory set size and visual set size for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

the rare leftovers may have made older observers' search less efficient.

The MVT makes explicit predictions about the optimal time point when a forager should leave the current patch and travel to the next in order to maximize the overall rate of acquisition, that is, be most efficient, in a nonexhaustive foraging task. The optimal forager should stay as long as the instantaneous rate of collection in the current patch is above the average rate of collection for the whole task, and otherwise leave (Charnov, 1976). Notably, this optimal point of leaving is determined independently from an observer's average rate of collection, which in turn depends on the individual RT. Since RT is affected by general age-related slowing (e.g., Cerella, 1985; Salthouse, 1996), we found substantial age group differences in the average RT, that is, the time between two consecutive clicks [younger: 1.12 s, older: 2.28 s, T(22) = 9.216, $p < .001$; $d = 3.762$ (95% CI 2.383, 5.111); BF10 = 1.341e^6], and in the time spent in one patch, that is, average time between onset of a new search display and the decision to press the "next" button [younger: 22.42 s, older: 48.80 s, T(22) = 8.11, $p < .001$; $d = 3.313$ (95% CI 2.038, 4.556); BF = 180172.380]. However, deviations from ideal foraging behavior according to MVT are relative and, therefore, independent of overall group differences in RT.

In Figure 5, the instantaneous rate of collection (the rate at which items are being collected) is plotted as a function of "reverse click" position (solid lines), for the last 10 clicks in each patch, for each block. Reverse clicks are measured from the end of collection in a patch. Thus, reverse click 1 is the last click on an item before the observer clicks on the "next" button to move to a new patch. Reverse click 2 is the penultimate click, reverse click 3 the one before that, and so forth. The instantaneous rate is computed as the reciprocal of the average RT multiplied by the probability that the item clicked is a target (i.e., 1 – false alarm rate). The average rates in items per second is computed for each memory set size (dashed lines) by dividing the total number of points for the block by the cumulative time (the sum of time spent in each patch plus travel time between patches).

The average rate of collection is much lower in older than younger observers [$F(1, 22) = 121.216$, $p < .001$, $\eta^2 = .846$ (90% CI .715, .892); BF10 = 4.880e^7], as expected, due to the overall slower average RT in the older group (see above). In addition, the average rate decreased with increasing Memory Set Size [$F(3, 66) = 52.865 < .001$, $\eta^2 = .706$ (90% CI .589, .760); BF10 = 1.802e^{13}], both in younger observers [$F(3, 33) = 31.909$, $p < .001$, $\eta^2 = .743$ (90% CI .572, .801); BF10 = 1.133e^7] and in older observers [$F(3, 33) = 22.231$, $p < .001$, $\eta^2 = .669$ (90% CI .462, .743); BF10 = 199635.838]. This reflects the fact that the memory search takes more time when there are more items in memory.

Turning to the predictions of MVT, as Figure 5 shows, the instantaneous rate falls continuously as the targets become de-

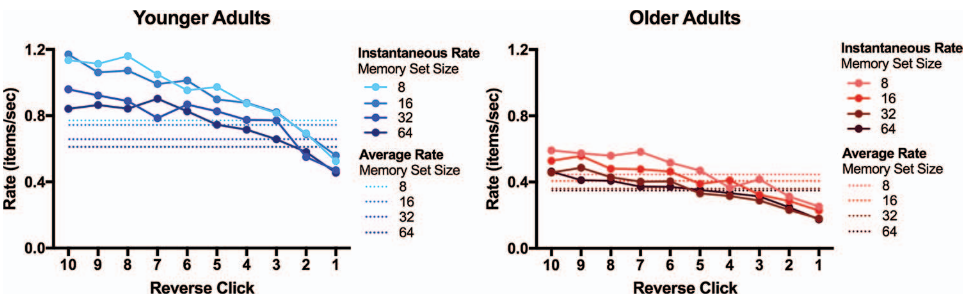

Figure 5. Instantaneous (data points) rates of collection of the last 10 clicks in a patch and average rate of collection (dotted lines), for each of the four memory set sizes for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. According to optimal foraging theory, observers should leave the patch when the instantaneous rate (data points) crosses the average rate (dotted line) of collection. See the online article for the color version of this figure.

pleted. In accordance with optimal foraging behavior according to MVT, younger observers appear to leave the patch as soon as the instantaneous rate falls below the average rate of collection. Older observers, however, seem to stay in the patch for another 2–3 clicks after the instantaneous rate has fallen below the average rate of collection.

Figure 6 helps to visualize the age differences in foraging. For each of the last three clicks in a patch, the figure plots the instantaneous rate against the average rate of collection for each memory set size in each age group. A simple MVT prediction would be that the last click in a patch should be the first click where the instantaneous rate falls below the average rate. This is what is seen, on average, in the younger sample's data. At the third reverse click, their instantaneous rate was significantly above the average rate for all memory set sizes [all $T(11) > 2.930$, $p < .015$, $d > 0.848$ (95% CI 0.169, 1.499); all $BF10 > 4.635$]. At the second reverse click, instantaneous and average rate did not differ [all $T(11) < 1.16$, $p > .25$, $d < 0.334$ (95% CI 0.254, 0.911); all $BF01 > 1.995$]. At the last click in the patch, the instantaneous rate tends to fall below the average rate, although these did not differ significantly except for the smallest memory set size [8: $T(11) = 4.678$, $p = .001$, $d = 1.351$ (90% CI 0.541, 2.129); $BF10 = 56.033$; 16–64: all $T < 1.60$, $p > .14$, $d < 0.447$ (95% CI −0.156, 1.1034); $BF01 > 1.344$]. For older observers, instantaneous and average rate did not differ for reverse click 3 [all $T(1,11) = 0.001$, $p > .090$, $d < 0.530$ (95% CI −0.079, 1.137); $BF01 > 0.925$]. At reverse click 2, the instantaneous rate dropped below the average rate, at least for higher memory set sizes [16–64: all $T(11) > 2.873$, $p < .015$, $d > 0.829$ (95% CI 0.155, 1.477); all $BF10 > 4.235$; memory set size 8: $T(11) = 1.812$, $p = .097$, $d = 0.523$ (95% CI −0.096, 1.336); $BF10 = 1.008$]. For the final click, the instantaneous rate was lower than the average rate for all memory set sizes [all $T(11) > 5.025$, $p < .001$, $d > 1.450$ (95% CI 0.612, 2.260); all $BF10 > 90.219$].

Replicating previous data (Wolfe et al., 2016), our results show that younger observers' behavior roughly follows the predictions of MVT: They left the patch when their instantaneous rate of collection was close to their average rate, making their foraging behavior "optimal" in MVT terms. In contrast, older observers stayed in their patches for a longer time, leaving only after the instantaneous rate of collection had fallen well below the average rate, making their foraging behavior less optimal. Importantly, older observers deviated from optimality according to MVT even under explicit instructions to think about moving if they thought it would speed the collection of points. Perhaps they were more "frugal," not wanting to "waste" targets. Whatever the explanation,

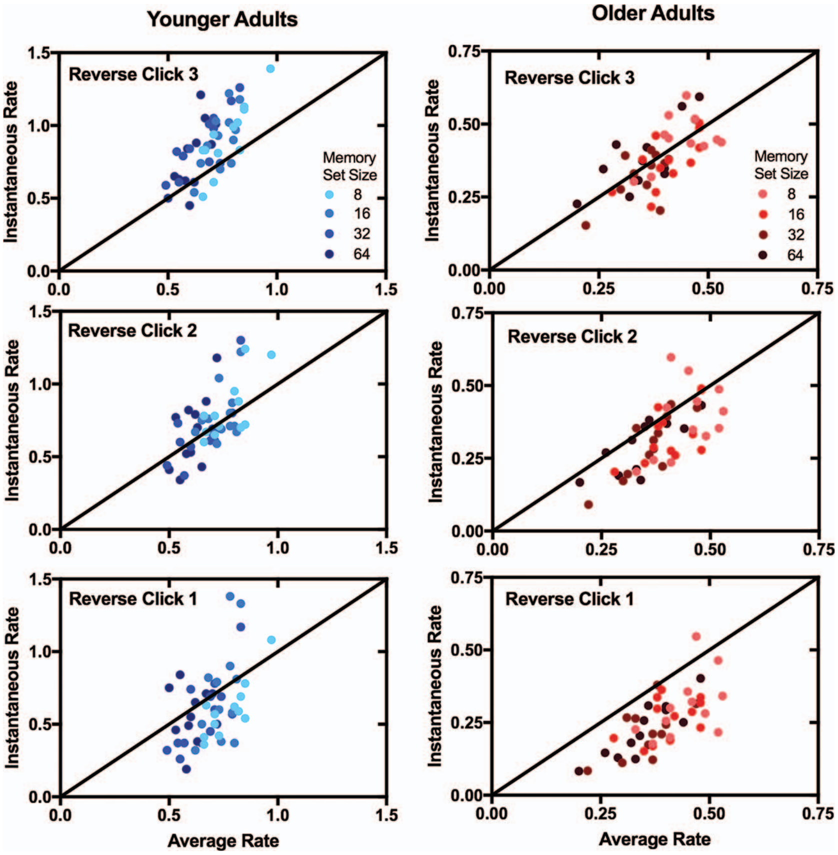

Figure 6. The plots show the instantaneous rate of collection for reverse click significantly 3–1 plotted against the average rate of collection for every observer at each of the four memory set sizes, for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. The diagonal line indicates equality between the instantaneous rate and average rate. See the online article for the color version of this figure.

aging appears to be associated with a shift toward a more conservative criterion when to leave a patch and move on to the next one. This age-related criterion shift was found under low and high memory load, indicating that task difficulty did not reduce the older observers' exploitative behavior (Hills et al., 2013; Liu et al., 2016).

Besides the instantaneous rate of collection, another driver for participants' decision to switch to a new patch may have been the occurrence of false alarms (i.e., erroneous clicks on distractor items). Figure 7 plots false alarm rates as a function of reverse click. Indeed, the last click in a patch was more likely to be a false alarm than clicks before. False alarm rates increased from the third reverse click to the last click in both age groups for memory set sizes 32 and 64 [all $T(11) > 2.47$, $p < .032$, $d > .716$ (95% CI 0.065, 1.481); $BF10 > 2.421$] and from the second reverse click to the last click in younger observers for memory set size 32 [$T(11) = 3.974$, $p = .002$, $d = 1.147$ (95% CI 0.394, 1.870); $BF10 = 20.789$] and for older observers for memory set sizes 32 and 64 [both $T(11) > 2.456$, $p < .033$, $d > 0.709$ (95% CI 0.060, 1.334); both $BF10 > 2.349$]. Thus, in the rare cases of errors, those might have contributed to the observers' decision to move on to the next patch. Importantly, however, false alarm rates did not differ between age groups, for any of the memory set size conditions, at reverse clicks 3–1 [all $T(22) < 1.222$, $p > .234$, $d < 0.490$ (95% CI 0.321, 1.306); all $BF01 > 1.567$]. Thus, it is unlikely that false alarms explain the age differences in the decision when to move on to the next patch.

Search Strategy Within a Patch: When do Observers Switch Between Targets?

In hybrid foraging tasks with multiple targets, Wolfe and colleagues (2016) demonstrated that younger observers typically pick in "runs" of the same target item rather than picking items randomly from all available targets in the patch (see also Wolfe et al., 2019). This suggests that switching to items of another target type within the patch imposes some costs. Alternatively, selecting one target type may prime that type (or make that target type's feature more salient due to perceptual grouping) so that targets of that type are favored for the next selection. The empirical consequences of these costs and/or benefits are the same: foragers tend to repeat the selection of the same type of target. That pressure, favoring runs, is countered by the decreasing instantaneous rate of collection as the currently selected target type becomes depleted (T. Kristjánsson & Kristjánsson, 2018). When search for the same target slows down, observers will at some point decide to switch to another target type. Described in those terms, selection of items within a patch can be thought of as a succession of smaller foraging episodes. Does this within-patch foraging behavior follow the predictions of MVT, and does it change with age?

Figure 8 shows the instantaneous rate of collection plotted as a function of reverse click position in run trials (1/RT). Here, reverse click measures the position of a collected target within a run of collecting the same target consecutively, again counted backward, this time from the last click in a run. As within the patch as a whole, the instantaneous rate of collection decreases within a run as this target type becomes depleted. The first click in the next run (also if this is a run of only one click) can be called a "switch" trial. The instantaneous rate of switch trials is plotted at the right end of the x-axes. We compared the instantaneous rate for the last click in a run (reverse click 1) and the instantaneous rate in switch trials with the average rate of collection within a patch, for each of the four memory sizes, in younger and older observers. The average rate within a patch was calculated as the time between the second and last click divided by the number of clicks in a patch. Note that, consequently, the average rate within a patch is smaller than the average rate in a block (i.e., over patches; see "Basic Foraging Behavior: When do Observers Move on to the Next Patch?" above), as the latter takes the travel time between patches and time to perform the first click in each patch into account.

The instantaneous rate of collection in the last click in a run (reverse click 1) was above the average rate in the patch for all set sizes, in younger observers [trend-significant for memory set size 8 $T(11) = 1.909$, $p = .083$, $d = 0.551$ (90% CI 0.069, 1.150); $BF10 = 1.135$; all other $T(11) > 4.020$, $p \leq .001$, $d > 1.161$ (90% CI 0.404, 1.887); all $BF10 > 22.230$] as well as older observers [all $T(11) > 2.936$, all $p < .015$; all $BF10 > 4.639$]. The instantaneous rate of collection in switch clicks, by contrast, was below the average rate in the patch for all set sizes, in younger observers [all $T(11) < 9.961$, $p < .001$, $d > 2.875$ (90% CI 1.552, 4.177); all $BF10 > 20994.927$] as well as older observers [all $T(11) < 9.457$, $p < .001$, $d > 2.729$ (90% CI 1.460, 3.978); all $BF10 > 13263.777$] (see Figure 9).

Thus, observers of both age groups searched in runs, which made their foraging more efficient. The groups also showed com-

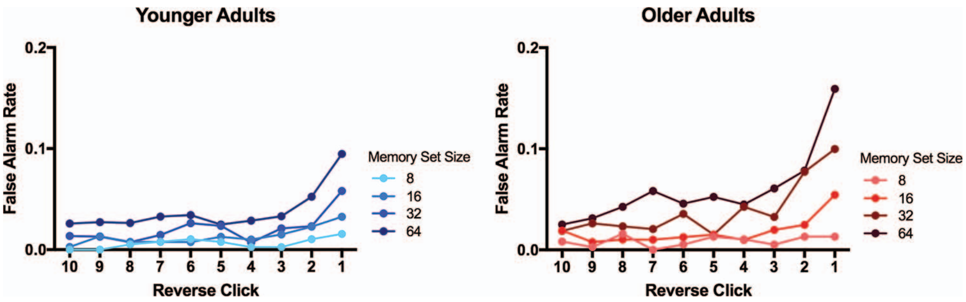

Figure 7. False alarm rates of the last 10 clicks in a patch, for each of the four memory set sizes for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

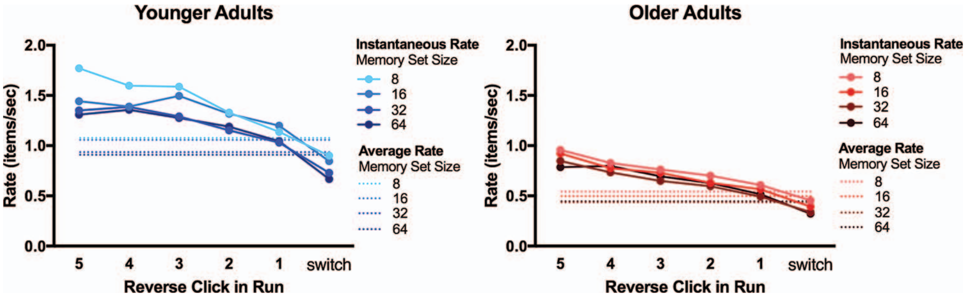

Figure 8. Instantaneous (data points) rates of return of the last 5 clicks in a run and switches, that is, first click in a run (circles), and average rate in a patch (dotted lines), for each of four memory set sizes for younger adults (left) and older adults (right). Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

parable costs of switching between target types in a patch. The mechanisms underlying facilitation of visual search and memory search in runs versus switches are discussed in more detail in the next section.

RT × Set Size Functions and General Slowing

Wolfe and colleagues (2019) argued that finding a target in a hybrid foraging search task places that target as a template in working memory, which guides attention to other items that share its visual features. This may explain the bias to repeat the selection of another instance of the previously selected item (i.e., search in runs). We examined the effects of prior selection on visual search efficiency and memory search efficiency and whether they would vary with age. Search efficiency is usually expressed in terms of the slope of the RT × set size function. In foraging experiments, with multiple targets and a visual set size that decreases each time an item is selected, the "effective visual set size" replaces the set size as the independent variable. The "effective visual set size" is computed as the current visual set size, divided by the number of targets present. RT × effective visual set size functions are plotted in Figure 10. We tested effects of Click Type (switch/run), Memory Set Size (8, 16, 32, 64), and Age (younger, older) on the slopes of these functions. For the raw RT, there was an effect of Click Type [$F(1, 22) = 18.151$, $p < .001$, $\eta^2 = .443$ (90% CI .176, .613); BF10 = 44.584], reflecting the shallower slopes for run trials compared to switch trials. There was also an effect of Age [$F(1, 22) = 25.458$, $p < .001$, $\eta^2 = .536$ (90% CI .265, .675); BF10 = 108.180], with older observers' slopes (run: 114 ms/item; switch: 172 ms/item) being steeper than younger observers' slopes (run: 34 ms/item; switch: 71 ms/item). There was no effect of

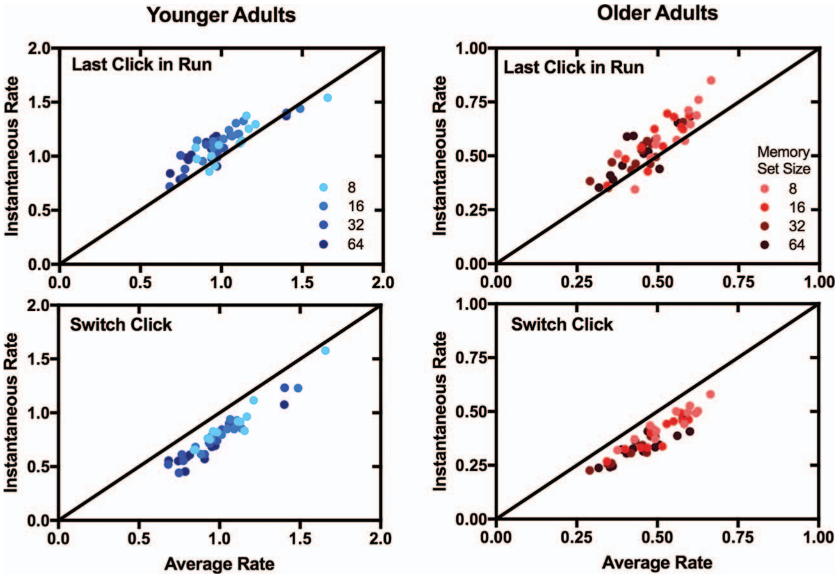

Figure 9. The plots show the instantaneous rates of collection for the last click in a run and switch clicks (first click in run) plotted against the average rate of collection for every observer at each of the four memory set sizes, for younger adults (left) and older adults (right). The diagonal line indicates equality between the instantaneous rate and average rate of collection. Darker colors (gray scales) indicate higher memory set sizes. See the online article for the color version of this figure.

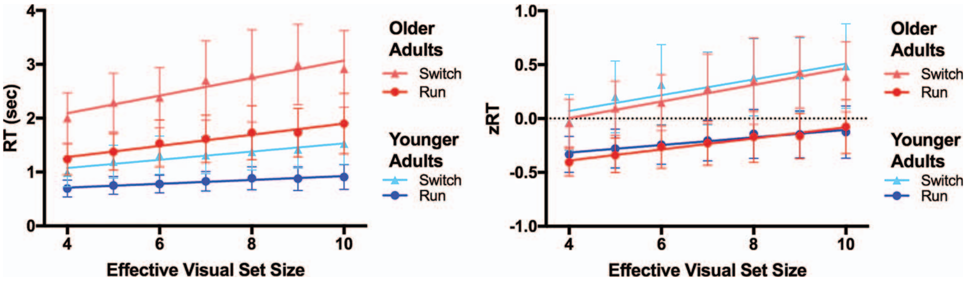

Figure 10. The reaction time (RT) × effective visual set size (total items/current targets) functions of the raw RT (left) and z-transformed RT (right) are plotted, across memory set sizes, for the two types of collection events (Run or Switch), for younger adults and older adults. Error bars indicate ±1 standard error of the mean. Circles and lighter color (gray scales) show data from runs and triangles and darker color (gray scale) show data from switches. See the online article for the color version of this figure.

Memory Set Size on slopes [$F(1, 22) = 0.454$, $p = .715$, $\eta^2 = .020$ (90% CI .000, .181); BF01 = 21.512], and no interactions of the factors [all $F < 0.806$, $p > .379$, $\eta^2 < .020$; all BF01 > 3.574]. The ANOVA on the slopes of the zRT × effective visual set size functions also revealed an effect of Click Type [$F(1, 22) = 9.217$, $p = .006$, $\eta^2 = .293$ (90% CI .056, .491); BF10 = 46.340]. There was no effect of Age [$F(1, 22) = 1.602$, $p = .219$, $\eta^2 = .068$ (90% CI .000, .263); BF01 = 2.695]. Again, the effect of Memory Set Size and none of the interactions were significant [all $F < 0.574$, $p > .635$; all BF01 > 4.015]. This pattern of results suggests that attention was guided toward the features of the previously selected target. The currently selected target biased subsequent visual search toward other items with features of that target, making visual search in runs more efficient than for target switches, in younger as well as in older observers. This mechanism is akin to intertrial repetition priming effects in single-target visual search, where observers are faster to respond when the target features are repeated over consecutive trials compared to when they change (Maljkovic & Nakayama, 1994, 2000; Müller, Heller, & Ziegler, 1995). This intertrial priming in single-target search tasks was shown to be preserved in older age (Madden, Whiting, Spaniol, & Bucur, 2005; McCarley et al., 2004; Wiegand et al., 2013). Introspectively, attention to one instance of an item may cause other instances of that item to appear more salient. For example, attending to a cat in a patch like in Figure 1 may make the observer more aware of the other cats. A switch of attention to a yellow flashlight will make her more aware of the group of those items. One could argue that this perceptual grouping is the cause of run behavior, or one could argue that both runs and perceived groups of targets are a consequence of the priming of the features of an attended target. Either way, observers, older and younger, are likely to pick another instance of the same target, if it is readily available. One argument against proposing that perceptual grouping is causal in the tendency to search in runs is that perceptual grouping is impaired in older age (Farkas & Hoyer, 1980; Gilmore, Tobias, & Royer, 1985), at least for certain stimulus features (Kurylo, 2006), whereas run behavior persists in our older sample group.

We computed the slope of the log RT × memory set size function, which is shown in Figure 11. Earlier findings reliably showed that RT increase logarithmically with memory set size in simple hybrid search (Cunningham & Wolfe, 2014; Wolfe, 2012; Wolfe et al., 2015). We recently demonstrated that the log shape of this function is preserved in older age (Wiegand & Wolfe, 2019) and that RTs also rise logarithmically with memory set size in hybrid foraging in younger observers (Wolfe et al., 2016). Accordingly, we examined RTs as a linear function of the log of the memory set size. We tested for effects of Click Type (switch/run) and Age (younger/older) on the slopes of these RT × memory set size functions. For the raw RT, the effects of Click Type and Age, as well as the interaction between the two factors, were significant [all $F(1, 22) > 7.747$, $p < .01$, $\eta^2 > .095$ (90% CI 0.038, 0.462); all BF10 > 1.670]. Slopes were shallower for runs than switches and

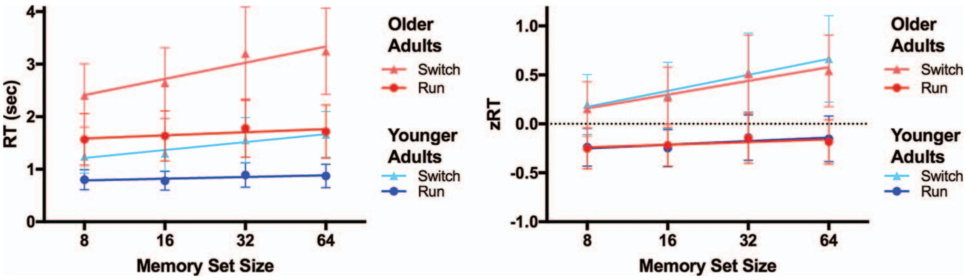

Figure 11. The reaction time (RT) × memory set size functions of the raw RT (left) and z-transformed RT (right) are plotted, across visual set sizes, on a logarithmic scale, for the two types of collection event (Run or Switch), for younger adults and older adults. Error bars indicate ± 1 standard error of the mean. Circles and lighter color (gray scales) show data from runs and triangles and darker color (gray scales) show data from switches. See the online article for the color version of this figure.

steeper in older observers (run: 84, ms/item; switch: 473 ms/item) than in younger observers (run: 48 ms/item; switch: 220 ms/item), and the difference between click types was larger in older than younger observers. For the slopes of the zRT × memory set size functions, however, there was only an effect of Click Type [$F(22, 1) = 63.950$, $p < .001$, $\eta^2 = .744$ (90% CI .546, .821); BF10 = 1.253e^8]. Correcting for individual differences in RT eliminated the effect of Age [$F(22, 1) = 0.489$, $p = .492$, $\eta^2 = .022$ (90% CI .000, .185); BF01 = 2.726] as well as the Age × Click Type interaction [$F(22, 1) = 0.009$, $p = .925$, $\eta^2 = .000$ (90% CI .000, .032); BF01 = 6.930]. This can be seen in Figure 11, right panel, in which the younger and older observers' data look essentially identical. These results confirm that repeating the previous selection speeds memory search, while switching between target items is slower (Wolfe et al., 2016). This mechanism does not appear to change with age.

Notably, once corrected for generalized slowing, the comparable zRT slopes imply that the relative RT difference between runs and switches, as well as the costs of adding more distractors to the display, were not higher in older age. This finding suggests that age-specific decline in visual search efficiency (Madden & Whiting, 2004) and increased distractibility in older age (McDowd & Shaw, 2000) do not affect performance in the hybrid foraging task. Similarly, the relative increase in RT with adding more targets to the memory set was similar for younger and older observers after correcting for the overall age-related slowing of RT. This may be even more surprising in the face of well-documented memory deficits in older age shown in other tasks (Grady & Craik, 2000). However, our results are in accordance with the absence of any qualitative age-related changes in simple hybrid search tasks (Wiegand & Wolfe, 2019).

General Discussion

In hybrid foraging, observers hold a set of target items in memory and collect multiple instances of those targets from a succession of visual patches. Performance in hybrid foraging can be analyzed in different ways, giving us information about various cognitive aspects that determine how efficiently we behave in rather complex search situations. In this study, we made use of the paradigm to pinpoint the sources of age-related deficits in such tasks.

Our results did not indicate that changes in basic cognitive processes affected older observers' performance in hybrid foraging. Certainly, there was a considerable increase in RT with age overall and, thus, decrease in the average rate of target collection. However, these age differences were largely explained by general age-related slowing, rather than qualitative differences between the groups (Rabbitt, 2017; Salthouse, 2016). The effects of memory set size on the number of missed targets, false alarms, average rate of collection, and transformed RT were similar in both age groups. These results confirm and expand upon what we have already demonstrated in simple hybrid search, where observers look for only one single target per trial. We found that the relative increase in RT with increasing memory set size up to 16 objects in memory, was similar across age groups (Wiegand & Wolfe, 2019). Here, we further show that even under higher memory load, with a memory set size up to 64 objects, there was no evidence for an age-specific impairment in memory search. Also, in line with our previous simple hybrid search experiments, the slopes of the RT × effective visual set size functions were similar in both age groups. The nonexistent age effects seem to be at odds with theories claiming that decline in attention and in memory are hallmarks of cognitive aging (Craik & Salthouse, 2008; Hoyer & Verhaeghen, 2006; Wang, Daselaar, & Cabeza, 2017). Experimental research has supported these theories, demonstrating age deficits in other visual search tasks (see Madden, 2007, for a review) and memory tasks (see Park & Festini, 2017, for a review). Some studies have demonstrated spared visual search performance in older adults (apart from general RT slowing). However, these were tasks in which attention was guided rather automatically by bottom-up feature contrasts, priming, predictive cues, or prior knowledge of a target-relevant feature (Madden, Whiting, Cabeza, & Huettel, 2004; Madden et al., 2005; Whiting, Madden, Pierce, & Allen, 2005).

We previously suggested that the picture material, for which discriminability and memory capacity is astonishingly good (Brady et al., 2008; Standing, 1973), may reduce age group differences in the hybrid search tasks. Likely, the meaningful pictures promote the instant build-up of perceptually and semantically relatively rich target representations, which facilitate both top-down guided visual search and memory retrieval, in younger as well as older observers (Madden & Plude, 1993; Plude & Hoyer, 1986). It has been argued that an item's meaning is encoded largely automatically due to lifelong learning and thus is less vulnerable to age-related memory decline (Hasher & Zacks, 1979). Indeed, earlier studies have shown that memory for pictures is largely equivalent across age groups (Park et al., 1996; A. D. Smith, Park, Cherry, & Berkovsky, 1990), while age-related decline was shown in search tasks using more confusable stimuli, such as letters, digits, and simple shapes (Madden, 1982; Madden & Whiting, 2004).

Besides good memory and visual selective attention in our older sample, we also show preserved priming-related facilitation of hybrid foraging search. Similar to the younger observers, older observers tended to select items of the same target type in runs within a patch. The RT × set size functions showed that both visual search and memory search were biased toward the previously selected target item, making search in runs more efficient compared to when observers switched between target types. This finding is in line with the assumption that automatic processes that influence attention and memory, such as repetition priming, are largely unaffected by aging (Jennings & Jacoby, 1993; McCarley et al., 2004; Wiegand et al., 2013). It is somewhat surprising, though, that both age groups also showed similar costs of switching between target types within a patch. Higher switch costs in older compared to younger adults are a ubiquitous finding in task-switching paradigms. This age effect was attributed to executive dysfunctions, specifically a deficit in deactivating the previously and activating the currently relevant task set (Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005). Accordingly, one may have expected that older observers have had difficulties in deactivating the current and retrieving a new search template from their activated long-term memory and therefore "get stuck" in runs. However, a recent meta-analysis showed that after accounting for general age-related slowing, the RT difference between switch and nonswitch trials in a task block did not differ between younger and older adults (Wasylyshyn, Verhaeghen, &

Sliwinski, 2011). It appears that the relative switch cost between target items in the hybrid foraging task are also age-invariant.

The most striking age differences we found in hybrid foraging were of a strategic nature. Younger observers, as previously shown (Wolfe et al., 2016), largely followed the predictions of optimal foraging behavior according to MVT. They tended to leave the current patch once their declining instantaneous rate of collection fell to their average rate of collection over the entire block. Older observers, by contrast, stayed in a patch until their instantaneous rate of collection dropped well below the average rate. Their behavior is, thus, suboptimal in MVT's terms of maximizing output per time (i.e., the present task goal). It has been shown that older adults choose less effective strategies than younger adults in other cognitive tasks and that these can lead to poorer performance (Brigham & Pressley, 1988; Lemaire, 2010; Price, Hertzog, & Dunlosky, 2008). In the present hybrid foraging example, this might be a strategic change in the trade-off between exploration and exploitation (Chin et al., 2015). Older adults seem to adopt a more conservative, exploitative strategy that encourages them to pick more targets than what is optimal if the goal is to maximize the rate of picking, taking time into account (which was the explicit instruction in the present experiment). If, on the other hand, the goal, implicit or explicit, was to not "waste" too many targets, then one might adopt the older observers' strategy of more exploitation and less exploration. This hypothesis is given some credence by the answers to the postexperiment questionnaire (see online supplemental materials). Many younger observers reported that they moved to the next patch whenever they were slowing down or could not recognize or locate a target easily. Older observers, on the other hand, were likely to report that they moved when no items were left behind. Perhaps, this tendency was reinforced by the feedback observers received about targets left behind in the practice block; although note that no feedback was given in the experimental block.

Interestingly, when we look at when observers move on to the next target type within a patch, we see that older observers did not stay too long in "runs" of collecting the same target. Like younger observers, they chose to switch readily to another target type when search in a run slowed down, before the instantaneous rate dropped below the average rate of collection in the patch. One important difference between the decision to move on to another patch versus the decision to move on to another target type within the same patch is the permanent nature of the move to a new patch. An observer could never go back to a previous patch while it was possible to switch back to searching for the previous target type within the same patch. How permanency of a decision might contribute to age differences in foraging needs further exploration.

While our task confirmed that exploitation increased with age, other search tasks have shown opposite effects (Hills et al., 2013; Mata et al., 2013). According to the cognitive control hypothesis by Mata and von Helversen (2015), this can be explained as the result of different cognitive requirements of exploration and exploitation in different tasks. Cognitive control is suggested to be a domain-general system that mediates the trade-off between exploitation and exploration. Thus, age-related changes in cognitive control may lead to either decreased or increased exploration and exploitation as a function of cognitive requirements of a given task. In the present task, age-related cognitive limitations like deficits in inhibiting distractors or memory retrieval did not affect performance. Under these circumstances, older observers could follow their (metacognitive) strategic bias to search exhaustively. Possibly, increasing the attention and memory load in hybrid foraging could result in a decrease in exploitation in older age. Specifically, older observers might leave targets behind because they are difficult to distinguish from distractors or dropped from memory. Alternatively, imposing a time limit on the task might encourage them to search less diligently.

To conclude, our results from this hybrid foraging search task show that differences in the search strategy, rather than a decline of basic cognitive functions, were the main driver of age differences in performance. Returning to our example, younger and older adults are equally likely to forget to pack stuffed bears into the travel bag. Older adults will, however, spend much more time to not miss any instance of the crayons scattered in the child's room. Importantly, hybrid foraging captures some aspects of real-world searches, where we often have multiple search goals on our minds that together determine the final behavior. The task provides us with a valuable framework to study individual differences, and specifically age-related changes, with relatively high ecological validity in a controlled way.

Limitations and Future Directions

In this study, we defined the optimal search strategy according to MVT. MVT provides a valid measure of "default" search efficiency under nonexhaustive search conditions, and we knew from prior work that younger adults largely follow the rules of MVT in the hybrid foraging task (Wolfe et al., 2016). The fact that MVT predicts behavior not only in human searchers, but across a wide range of species, such as monkeys (Hayden, Pearson, & Platt, 2011), rats (Mellgren, 1982), birds (Ydenberg, 1984), and insects (Wajnberg, Fauvergue, & Pons, 2000), lets us assume that explicit instructions about how to optimize patch-leaving behavior and conscious awareness of the rule are not necessary. Older adults appear to deviate from this the most straightforward prediction of MVT, shifting toward a more conservative quitting rule. With explicit instructions, they could possibly be trained to be more "optimal" in their quitting criterion. This could be an interesting direction for future research.

Furthermore, search tasks in the real world are multifaceted. In some situations, it may be important to find all targets and leave as few as possible behind. In the grandchild search, proposed at the outset, it might not be important to collect every crayon but it might be critical to find every stuffed bear. Similarly, if a radiologist is "foraging" for metastases of cancer, it is important to find all of them. We know from previous research that younger observers deviate from MVT when they are instructed to forage exhaustively (Wolfe, 2013). It would be interesting to test whether age differences in hybrid foraging decrease under exhaustive search conditions, where the observer is required to collect all targets (Á. Kristjansson et al., 2014).

Future studies may now add another level of complexity to tasks, for example, by enforcing strategic adaptations according to environmental conditions (e.g., prevalence of targets/distractors) or observer-specific, motivational aspects (e.g., value and reward representations). It would be highly interesting to investigate interindividual and age differences in hybrid foraging under various conditions using a larger sample size than in the present study and considering mediating observer variables, such as personality traits or sex. Notably, the gender distribution in the present study was shifted to more females than males in the younger group. Most previous research showed that cognitive sex differences are generally small (Hyde, 2005, 2014), suggesting that our results are largely generalizable across male and female observers. Future studies, however, should aim for larger samples with balanced gender distributions across age groups to control for potential sex differences in performance. Another question for future research is the generalizability of the age effects to other tasks that are not primarily visual and require strategic self-regulation, such as foraging-like behavior in internal information search (Chin, Anderson, et al., 2015; Hills & Dukas, 2012; Hills, Jones, & Todd, 2012; Pirolli, 2007).

References

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences, 16,* 437–443. http://dx.doi.org/10.1016/j.tics.2012.06.010

Blair, J. R., & Spreen, O. (1989). Predicting premorbid IQ: A revision of the National Adult Reading Test. *Clinical Neuropsychologist, 3,* 129–136. http://dx.doi.org/10.1080/13854048908403285

Boettcher, S. E., & Wolfe, J. M. (2015). Searching for the right word: Hybrid visual and memory search for words. *Attention, Perception, & Psychophysics, 77,* 1132–1142. http://dx.doi.org/10.3758/s13414-015-0858-9

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences of the United States of America, 105,* 14325–14329. http://dx.doi.org/10.1073/pnas.0803390105

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10,* 433–436. http://dx.doi.org/10.1163/156856897X00357

Brigham, M. C., & Pressley, M. (1988). Cognitive monitoring and strategy choice in younger and older adults. *Psychology and Aging, 3,* 249–257. http://dx.doi.org/10.1037/0882-7974.3.3.249

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology, 21,* 1–16. http://dx.doi.org/10.1111/j.2044-8260.1982.tb01421.x

Broady, T., Chan, A., & Caputi, P. (2010). Comparison of older and younger adults' attitudes towards and abilities with computers: Implications for training and learning. *British Journal of Educational Technology, 41,* 473–485. http://dx.doi.org/10.1111/j.1467-8535.2008.00914.x

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67–83. http://dx.doi.org/10.1037/0033-2909.98.1.67

Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. *Theoretical Population Biology, 9,* 129–136. http://dx.doi.org/10.1016/0040-5809(76)90040-X

Chin, J., Anderson, E., Chin, C. L., & Fu, W. T. (2015). Age differences in information search: An exploration-exploitation tradeoff model. *Proceedings of the Human Factors and Ergonomics Society annual meeting* (Vol. 59, pp. 85–89). Los Angeles, CA: Sage. http://dx.doi.org/10.1177/1541931215591018

Chin, J., Fu, W. T., & Kannampallil, T. (2009). Adaptive information search: Age-dependent interactions between cognitive profiles and strategies. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 1683–1692). Boston, MA: ACM Press.

Chin, J., Payne, B. R., Fu, W. T., Morrow, D. G., & Stine-Morrow, E. A. (2015). Information foraging across the life span: Search and switch in unknown patches. *Topics in Cognitive Science, 7,* 428–450. http://dx.doi.org/10.1111/tops.12147

Craik, F. I., & Bialystok, E. (2006). Cognition through the lifespan: Mechanisms of change. *Trends in Cognitive Sciences, 10,* 131–138. http://dx.doi.org/10.1016/j.tics.2006.01.007

Craik, F. I. M., & Salthouse, T. A. (Eds.). (2008). *The handbook of aging and cognition* (3rd ed.). New York, NY: Psychology Press.

Cunningham, C. A., & Wolfe, J. M. (2014). The role of object categories in hybrid visual and memory search. *Journal of Experimental Psychology: General, 143,* 1585–1599. http://dx.doi.org/10.1037/a0036313

Farkas, M. S., & Hoyer, W. J. (1980). Processing consequences of perceptual grouping in selective attention. *Journal of Gerontology, 35,* 207–216. http://dx.doi.org/10.1093/geronj/35.2.207

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125,* 777–799. http://dx.doi.org/10.1037/0033-2909.125.6.777

Fleischman, D. A., & Gabrieli, J. D. (1998). Repetition priming in normal aging and Alzheimer's disease: A review of findings and theories. *Psychology and Aging, 13,* 88–119. http://dx.doi.org/10.1037/0882-7974.13.1.88

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198. http://dx.doi.org/10.1016/0022-3956(75)90026-6

Gilmore, G. C., Tobias, T. R., & Royer, F. L. (1985). Aging and similarity grouping in visual search. *Journal of Gerontology, 40,* 586–592. http://dx.doi.org/10.1093/geronj/40.5.586

Grady, C. L., & Craik, F. I. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology, 10,* 224–231. http://dx.doi.org/10.1016/S0959-4388(00)00073-8

Grahame, M., Laberge, J., & Scialfa, C. T. (2004). Age differences in search of web pages: The effects of link size, link number, and clutter. *Human Factors, 46,* 385–398. http://dx.doi.org/10.1518/hfes.46.3.385.50404

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108,* 356–388. http://dx.doi.org/10.1037/0096-3445.108.3.356

Hayden, B. Y., Pearson, J. M., & Platt, M. L. (2011). Neuronal basis of sequential foraging decisions in a patchy environment. *Nature Neuroscience, 14,* 933–939. http://dx.doi.org/10.1038/nn.2856

Hills, T. T., & Dukas, R. (2012). The evolution of cognitive search. In P. M. Todd, T. T. Hills, & T. W. Robbins (Eds.), *Cognitive search: Evolution, algorithms, and the brain* (pp. 11–24). Cambridge, MA: MIT Press.

Hills, T. T., Jones, M. N., & Todd, P. M. (2012). Optimal foraging in semantic memory. *Psychological Review, 119,* 431–440. http://dx.doi.org/10.1037/a0027373

Hills, T. T., Mata, R., Wilke, A., & Samanez-Larkin, G. R. (2013). Mechanisms of age-related decline in memory search across the adult life span. *Developmental Psychology, 49,* 2396–2404. http://dx.doi.org/10.1037/a0032272

Ho, G., Scialfa, C. T., Caird, J. K., & Graw, T. (2001). Visual search for traffic signs: The effects of clutter, luminance, and aging. *Human Factors, 43,* 194–207. http://dx.doi.org/10.1518/001872001775900922

Hoyer, W. J., & Verhaeghen, P. (2006). Memory aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (6th ed., pp. 209–232). London: Elsevier.

Hyde, J. S. (2005). The gender similarities hypothesis. *American Psychologist, 60,* 581–592. http://dx.doi.org/10.1037/0003-066X.60.6.581

Hyde, J. S. (2014). Gender similarities and differences. *Annual Review of Psychology, 65,* 373–398. http://dx.doi.org/10.1146/annurev-psych-010213-115057

Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging, 8,* 283–293. http://dx.doi.org/10.1037/0882-7974.8.2.283

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica, 101,* 339–378. http://dx.doi.org/10.1016/S0001-6918(99)00011-6

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15,* 126–147. http://dx.doi.org/10.1037/0882-7974.15.1.126

Kristjánsson, Á., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Attention, Perception, & Psychophysics, 72,* 5–18. http://dx.doi.org/10.3758/APP.72.1.5

Kristjánsson, Á., Jóhannesson, Ó. I., & Thornton, I. M. (2014). Common attentional constraints in visual foraging. *PLoS ONE, 9,* e100752. http://dx.doi.org/10.1371/journal.pone.0100752

Kristjánsson, T., & Kristjánsson, Á. (2018). Foraging through multiple target categories reveals the flexibility of visual working memory. *Acta Psychologica, 183,* 108–115. http://dx.doi.org/10.1016/j.actpsy.2017.12.005

Kurylo, D. D. (2006). Effects of aging on perceptual organization: Efficacy of stimulus features. *Experimental Aging Research, 32,* 137–152. http://dx.doi.org/10.1080/03610730600553901

Laver, G. D., & Burke, D. M. (1993). Why do semantic priming effects increase in old age? A meta-analysis. *Psychology and Aging, 8,* 34–43. http://dx.doi.org/10.1037/0882-7974.8.1.34

Lemaire, P. (2010). Cognitive strategy variations during aging. *Current Directions in Psychological Science, 19,* 363–369. http://dx.doi.org/10.1177/0963721410390354

Liu, X., Chin, J., Payne, B. R., Fu, W. T., Morrow, D. G., & Stine-Morrow, E. A. (2016). Adult age differences in information foraging in an interactive reading environment. *Psychology and Aging, 31,* 211–223. http://dx.doi.org/10.1037/pag0000079

Madden, D. J. (1982). Age differences and similarities in the improvement of controlled search. *Experimental Aging Research, 8,* 91–98.

Madden, D. J. (2007). Aging and visual attention. *Current Directions in Psychological Science, 16,* 70–74. http://dx.doi.org/10.1111/j.1467-8721.2007.00478.x

Madden, D. J., & Plude, D. J. (1993). Selective preservation of selective attention. In J. Cerella, J. Rybash, W. Hoyer, & M. L. Commons (Eds.), *Adult information processing: Limits on loss* (pp. 273–300). San Diego, CA: Academic Press.

Madden, D. J., & Whiting, W. L. (2004). Age-related changes in visual attention. In P. T. Costa & I. C. Siegler (Eds.), *Recent advances in psychology and aging* (pp. 41–88). Amsterdam, the Netherlands: Elsevier.

Madden, D. J., Whiting, W. L., Cabeza, R., & Huettel, S. A. (2004). Age-related preservation of top-down attentional guidance during visual search. *Psychology and Aging, 19,* 304–309.

Madden, D. J., Whiting, W. L., Spaniol, J., & Bucur, B. (2005). Adult age differences in the implicit and explicit components of top-down attentional guidance during visual search. *Psychology and Aging, 20,* 317–329. http://dx.doi.org/10.1037/0882-7974.20.2.317

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition, 22,* 657–672. http://dx.doi.org/10.3758/BF03209251

Maljkovic, V., & Nakayama, K. (2000). Priming of popout: III. A short-term implicit memory system beneficial for rapid target selection. *Visual Cognition, 7,* 571–595. http://dx.doi.org/10.1080/135062800407202

Mata, R., & von Helversen, B. (2015). Search and the aging mind: The promise and limits of the cognitive control hypothesis of age differences in search. *Topics in Cognitive Science, 7,* 416–427. http://dx.doi.org/10.1111/tops.12139

Mata, R., Wilke, A., & Czienskowski, U. (2009). Cognitive aging and adaptive foraging behavior. *The Journals of Gerontology: Series B, 64B,* 474–481. http://dx.doi.org/10.1093/geronb/gbp035

Mata, R., Wilke, A., & Czienskowski, U. (2013). Foraging across the life span: Is there a reduction in exploration with aging? *Frontiers in Neuroscience, 7,* 53. http://dx.doi.org/10.3389/fnins.2013.00053

Mather, M. (2006). A review of decision-making processes: Weighing the risks and benefits of aging. In L. L. Carstensen & C. R. Hartel (Eds.), *When I'm 64* (pp. 145–173). Washington, DC: National Academies Press.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16,* 96–109. http://dx.doi.org/10.1037/0882-7974.16.1.96

McCarley, J. S., Kramer, A. F., Colcombe, A. M., & Scialfa, C. T. (2004). Priming of pop-out in visual search: A comparison of young and old adults. *Aging, Neuropsychology, and Cognition, 11,* 80–88. http://dx.doi.org/10.1076/anec.11.1.80.29362

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging: A functional perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 221–292). Mahwah, NJ: Erlbaum.

Mellgren, R. L. (1982). Foraging in a simulated natural environment: There's a rat loose in the lab. *Journal of the Experimental Analysis of Behavior, 38,* 93–100. http://dx.doi.org/10.1901/jeab.1982.38-93

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7,* 134–140.

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton feature targets within and across feature dimensions. *Perception & Psychophysics, 57,* 1–17. http://dx.doi.org/10.3758/BF03211845

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187. http://dx.doi.org/10.1037/0278-7393.26.5.1170

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254. http://dx.doi.org/10.1037/0096-3445.106.3.226

Nelson, H. E. (1982). *National Adult Reading Test (NART): For the assessment of premorbid intelligence in patients with dementia: Test manual*. London, England: NFER-Nelson.

Nucci, M., Mapelli, D., & Mondini, S. (2012). Cognitive Reserve Index questionnaire (CRIq): A new instrument for measuring cognitive reserve. *Aging Clinical and Experimental Research, 24,* 218–226.

Park, D. C., & Festini, S. B. (2017). Theories of memory and aging: A look at the past and a glimpse of the future. *The Journals of Gerontology: Series B, 72,* 82–90. http://dx.doi.org/10.1093/geronb/gbw066

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11,* 621–637. http://dx.doi.org/10.1037/0882-7974.11.4.621

Pirolli, P. (2007). *Information foraging theory: Adaptive interaction with information*. New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780195173321.001.0001

Plude, D. J., & Hoyer, W. J. (1986). Age and the selectivity of visual information processing. *Psychology and Aging, 1,* 4–10.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, N.: Erlbaum.

Price, J., Hertzog, C., & Dunlosky, J. (2008). Age-related differences in strategy knowledge updating: Blocked testing produces greater improvements in metacognitive accuracy for younger than older adults. *Neuropsychology, Aging, Neuropsychology, and Cognition, 15,* 601–626. http://dx.doi.org/10.1080/13825580801956225

Pyke, G. H. (1978). Optimal foraging in hummingbirds: Testing the marginal value theorem. *American Zoologist, 18,* 739–752. http://dx.doi.org/10.1093/icb/18.4.739

Rabbitt, P. (2017). Speed of visual search in old age: 1950 to 2016. *The Journals of Gerontology: Series B, 72,* 51–60. http://dx.doi.org/10.1093/geronb/gbw097

Radloff, L. S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement, 1,* 385–401. http://dx.doi.org/10.1177/014662167700100306

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology, 41,* 661–671. http://dx.doi.org/10.1037/0012-1649.41.4.661

Rouder, J. N., Morey, R. D., Speckman, P. L., & Province, J. M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology, 56,* 356–374. http://dx.doi.org/10.1016/j.jmp.2012.08.001

Rouder, J. N., Morey, R. D., Verhagen, J., Swagman, A. R., & Wagenmakers, E. J. (2017). Bayesian analysis of factorial designs. *Psychological Methods, 22,* 304–321. http://dx.doi.org/10.1037/met0000057

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428. http://dx.doi.org/10.1037/0033-295X.103.3.403

Salthouse, T. A. (2016). *Theoretical perspectives on cognitive aging*. London, United Kingdom: Psychology Press. http://dx.doi.org/10.4324/9781315785363

Smith, A. D., Park, D. C., Cherry, K., & Berkovsky, K. (1990). Age differences in memory for concrete and abstract pictures. *Journal of Gerontology, 45,* P205–P210. http://dx.doi.org/10.1093/geronj/45.5.P205

Smith, G. A., & Brewer, N. (1995). Slowness and age: Speed-accuracy mechanisms. *Psychology and Aging, 10,* 238–247. http://dx.doi.org/10.1037/0882-7974.10.2.238

Sperber, R. D., McCauley, C., Ragain, R. D., & Weil, C. M. (1979). Semantic priming effects on picture and word processing. *Memory & Cognition, 7,* 339–345. http://dx.doi.org/10.3758/BF03196937

Standing, L. (1973). Learning 10000 pictures. *Quarterly Journal of Experimental Psychology, 25,* 207–222.

Stanovich, K. (2011). *Rationality and the reflective mind*. New York, NY: Oxford University Press.

Starns, J. J., & Ratcliff, R. (2010). The effects of aging on the speed-accuracy compromise: Boundary optimality in the diffusion model. *Psychology and Aging, 25,* 377–390. http://dx.doi.org/10.1037/a0018022

Starns, J. J., & Ratcliff, R. (2012). Age-related differences in diffusion model boundary optimality with both trial-limited and time-limited tasks. *Psychonomic Bulletin & Review, 19,* 139–145. http://dx.doi.org/10.3758/s13423-011-0189-3

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society, 8,* 448–460. http://dx.doi.org/10.1017/S1355617702813248

Theeuwes, J. (2018). Visual selection: Usually fast and automatic; seldom slow and volitional; a reply to commentaries *Journal of Cognition, 1,* 21. http://dx.doi.org/10.5334/joc.32

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., . . . Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review, 25,* 58–76. http://dx.doi.org/10.3758/s13423-017-1323-7

Wajnberg, E., Fauvergue, X., & Pons, O. (2000). Patch leaving decision rules and the Marginal Value Theorem: An experimental analysis and a simulation model. *Behavioral Ecology, 11,* 577–586. http://dx.doi.org/10.1093/beheco/11.6.577

Wang, W. C., Daselaar, S. M., & Cabeza, R. (2017). Episodic memory decline and healthy aging. In J. P. Stein (Ed.), *Reference module in neuroscience and biobehavioral psychology* (2nd ed., pp. 476–496). Amsterdam: Elsevier.

Wasylyshyn, C., Verhaeghen, P., & Sliwinski, M. J. (2011). Aging and task switching: A meta-analysis. *Psychology and Aging, 26,* 15–20. http://dx.doi.org/10.1037/a0020912

Wechsler, D. (1958). *The measurement and appraisal of adult intelligence*. Baltimore, MD: Williams & Wilkens. http://dx.doi.org/10.1037/11167-000

Whiting, W. L., Madden, D. J., Pierce, T. W., & Allen, P. A. (2005). Searching from the top down: Ageing and attentional guidance during singleton detection. *The Quarterly Journal of Experimental Psychology Section A, 58,* 72–97. http://dx.doi.org/10.1080/02724980443000205

Wiegand, I., Finke, K., Müller, H. J., & Töllner, T. (2013). Event-related potentials dissociate perceptual from response-related age effects in visual search. *Neurobiology of Aging, 34,* 973–985. http://dx.doi.org/10.1016/j.neurobiolaging.2012.08.002

Wiegand, I., & Wolfe, J. M. (2019). Age doesn't matter much: Hybrid visual and memory search is preserved in older adults. *Aging, Neuropsychology, and Cognition*. Advance online publication. http://dx.doi.org/10.1080/13825585.2019.1604941

Wolfe, J. M. (2012). Saved by a log: How do humans perform hybrid visual and memory search? *Psychological Science, 23,* 698–703. http://dx.doi.org/10.1177/0956797612443968

Wolfe, J. M. (2013). When is it time to move to the next raspberry bush? Foraging rules in human visual search. *Journal of Vision, 13*(3), 10.

Wolfe, J. M., Aizenman, A. M., Boettcher, S. E., & Cain, M. S. (2016). Hybrid foraging search: Searching for multiple instances of multiple types of target. *Vision Research, 119,* 50–59. http://dx.doi.org/10.1016/j.visres.2015.12.006

Wolfe, J. M., Boettcher, S. E., Josephs, E. L., Cunningham, C. A., & Drew, T. (2015). You look familiar, but I don't care: Lure rejection in hybrid visual and memory search is not based on familiarity. *Journal of Experimental Psychology: Human Perception and Performance, 41,* 1576–1587. http://dx.doi.org/10.1037/xhp0000096

Wolfe, J. M., Cain, M. S., & Aizenman, A. M. (2019). Guidance and selection history in hybrid foraging visual search. *Attention, Perception, & Psychophysics, 81,* 637–653. http://dx.doi.org/10.3758/s13414-018-01649-5

Ydenberg, R. C. (1984). Great tits and giving-up times: Decision rules for leaving patches. *Behaviour, 90,* 1–24. http://dx.doi.org/10.1163/156853984X00533

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46,* 441–517.

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