

# Cognitive Aging and Adaptive Foraging Behavior

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**We conducted two experiments comparing younger and older adults' ability to adjust their foraging behavior as a function of task characteristics. Participants foraged for fish in a virtual landscape and had to decide when to move between ponds so as to maximize the number of fish caught. In the first experiment, participants were left to generate their own foraging strategy, whereas in the second experiment, participants were instructed to use an incremental strategy that has been shown to produce optimal performance in this task. Our results suggest that both younger and older adults are adaptive in the sense of adjusting the parameters of their foraging strategy as a function of task characteristics. Nevertheless, older adults show overall poorer performance compared with younger adults even when instructed to use an optimal strategy.**

**Key Words:** Aging—Decision making—Foraging—Strategy.

THE idea that people are adaptive in their strategy use has good standing in the psychological literature (Baltes & Baltes, 1990; Gigerenzer, Todd, & the ABC Research Group, 1999; Payne, Bettman, & Johnson, 1993; Schunn & Reder, 2001; Siegler & Lemaire, 1997). However, research on aging suggests that there may be age-related changes in strategy selection and application (e.g., Dunlosky & Hertzog, 1998; El Yagoubi, Lemaire, & Besson, 2005; Lemaire, Arnaud, & Lecacheur, 2004; Mata, Schooler, & Rieskamp, 2007; Touron & Hertzog, 2004). Mata and colleagues showed that due to cognitive limitations, a significant number of older adults had to default to simpler decision strategies even when more complex strategies were more rewarding. Similarly, Lemaire and colleagues asked younger and older adults to provide estimates of multiplication problems and showed that although younger and older adults have similar strategy preferences, older adults choose less often the appropriate strategy for a given problem. Moreover, Lemaire and colleagues found that older adults were slower and made more errors when applying a given strategy. Consequently, aging research suggests that there are age-related differences in the ability to adaptively select as well as efficiently apply strategies. However, age differences in strategy selection and application are not found across the board (cf. Salthouse, 1991). Aging researchers have found sustained or improved strategy use in older age in some domains, such as spatial cognition and arithmetic division (e.g., Cohen & Faulkner, 1983; Geary & Wiley, 1991). In the present work, we contribute to the effort of mapping the circumstances in which aging affects strategy selection and application by examining younger and older adults' ability to adapt to environmental characteristics in an unexplored domain concerning age-related change: foraging behavior. The foraging domain may prove a particularly fruitful one to investigate the impact of aging on

strategy adaptivity because we have a good understanding of how and when different foraging strategies work (see Wilke, Hutchinson, Todd, & Czienskowski, 2009).

Foraging, the act of searching for resources, is a nontrivial problem for humans and other animals (e.g., Bell, 1991; Fortin, 2003). Consider a picky forager searching for a restaurant in a city he does not know, say Berlin. The forager randomly strolls the streets in search of a good restaurant. Once he visited many restaurants in a given *Kiez* (i.e., neighborhood) and found none that meets his fancy, staying longer in that area is wasteful because it would take a long time to find the next unvisited restaurant: He would do better to move to another *Kiez* where the initial rate of encounter is higher. Conversely, it would be wasteful to leave a *Kiez* too early because of the travel costs of moving from *Kiez* to *Kiez* (Berlin is famous for being spread out). What our forager needs is a decision rule timing the moment of departure based on previous successes in several neighborhoods.

The problem of patch departure has been addressed formally (Charnov, 1976) and researchers have proposed a number of suitable decision strategies and calculated in what kind of environments each works well (e.g., Iwasa, Higashi, & Yamamura, 1981; van Alphen, Bernstein, & Driessen, 2003; Wilke et al., 2009). For example, the incremental rule is one strategy that has been shown to work well in aggregated environments, that is, environments in which most patches are poor but a minority possesses many resources—a few neighborhoods have all the good restaurants. The strategy underlying the incremental rule can be described as follows. First, set an initial tendency to stay in a neighborhood (patch) upon entering and decrease this tendency steadily with time (e.g., linearly). Subsequently, increment the current staying tendency with each successful catch or, if the decreasing tendency crosses a lower threshold, leave the current patch. The rationale why an incremental rule fits

well the structure of an aggregated environment is that encountering the desired item in a particular patch is a cue signaling one may have hit the jackpot (one of the rare rich patches) and, thus, should stay in that patch. In contrast, in a poor patch, the tendency to stay will decrease rapidly until the threshold is met (Stephens & Krebs, 1987).

Younger adults are adaptive albeit not optimal foragers (Hutchinson, Wilke, & Todd, 2008; Pirolli, 2007). For example, Hutchinson and colleagues found that younger adults were able to adjust their foraging behavior as a function of travel time between patches albeit their strategy parameters deviated from the optimality predictions. Our research extended this line of work to investigate older adults' foraging abilities. In particular, we asked whether younger and older adults are equally able to adjust the parameters of an incremental strategy to adapt to different travel times between patches. Overall, our expectation was that age-related differences in performance would emerge due to differences in both strategy selection and application (Siegler & Lemaire, 1997). First, aging has been associated with deficits in strategy selection (Lemaire et al., 2004; Mata et al., 2007), suggesting that we may find considerable differences in strategy use when individuals have to produce their own strategies and adjust these to the problem at hand without instruction. Second, aging is associated with differences in strategy application even when controlling for strategy selection (Lemaire et al., 2005). Aging leads to a decline in the ability to learn associations (Kausler, 1994) and this can have implications for learning the statistical structure of environments (e.g., Mutter & Pilske, 1994; Mutter & Williams, 2004; Sanford & Maule, 1973; Wood, Busemeyer, Koling, Cox, & Davis, 2005) and ultimately setting strategy parameters. For example, Wood and colleagues have shown that older adults have problems learning the value of differentially lucrative options over time in a decision-making task. Similarly, our task required setting a parameter—initial staying time—as a function of task characteristics that had to be learned over time: Participants were not instructed about the distribution of resources or travel time between patches but had to learn these throughout the task, which could prove particularly hard for older adults even when told which strategy to employ. Consequently, even in conditions in which strategy selection components are controlled for, older adults may nonetheless show worse performance compared with younger adults due to difficulties in setting the appropriate strategy parameter.

## EXPERIMENT 1

Participants foraged for fish in a sequence of ponds and decided on how long to stay at each pond (see Figure 1a for the underlying distribution of fish). When participants decided to switch ponds, they incurred a cost of a constant travel time between ponds. Each participant experienced two environments, one in which the travel time between

ponds was short and one with a long travel time. We were interested in assessing how well younger and older adults' foraging behavior matched the optimal policy for the environments considered. Figure 1b shows the optimality predictions obtained using dynamic programming (see Houston & McNamara, 1999, for an overview). We keep with the behavioral ecology literature tradition of plotting the relation of time on items captured with time on the  $x$ -axis (e.g., Iwasa et al., 1981). The optimal policies for the two environments are very similar, as both possess an aggregated distribution of resources. The optimal policy is to have a finite initial waiting time when entering a patch and increment it whenever one item is found—the incremental rule. The jagged lines in Figure 1b show the points at which a subject should switch to maximize rate of resource intake for the two environments. The lines indicate that the increments in waiting time with each capture are virtually the same for the two environments. The main difference between the predictions concerns the initial time one should be willing to wait at a pond without finding fish: The initial staying time should be longer for an environment with a longer travel time. The rationale behind this prediction is that longer delays represent higher costs in accessing patches, which makes it important to exploit the patches more thoroughly to maximize resource intake. In sum, our experiment allowed us to test whether younger and older adults adjust their policies as a function of the different travel time between patches, specifically, whether they show a longer initial staying time in an environment with a longer travel time.

## Method

*Participants.*—Forty-five younger adults (27 women) and 45 older adults (23 women) participated in Experiment 1 (see participants' characteristics in Table 1). The majority of younger adults were students from the Free University of Berlin, and the majority of older adults were retirees recruited from the community. Younger and older participants were matched on the number of years of formal education. Participants were paid a fee for their participation in the experiment (€10 per hour), which took about 2 hr, plus a bonus relative to how well they did in the foraging task (€0.10 per fish caught).

*Design.*—The experiment had two within-subject conditions differing in the travel time between ponds (15 s, short travel time; 35 s, long travel time). The order of presentation of the environments was counterbalanced across participants.

*Procedure.*—Before beginning the experiment, participants were told that the foraging task would take around 1.5 hr and were asked to put aside any devices (e.g., watches, cell phones) that could be used as external timekeepers.

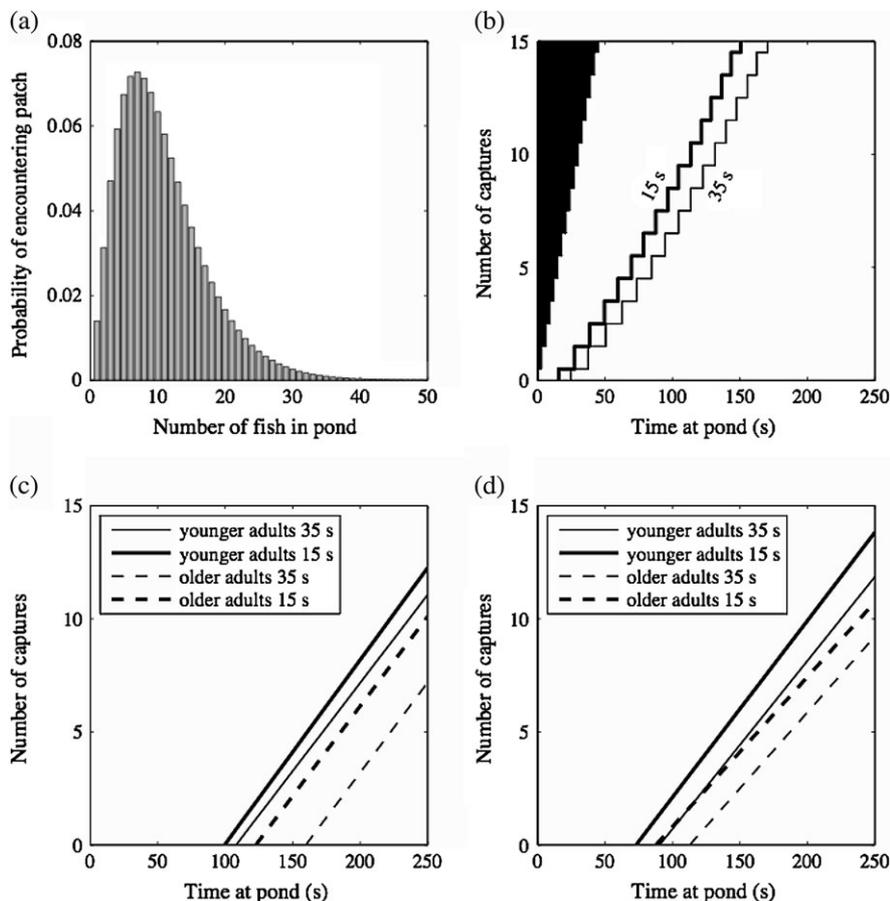


Figure 1. (a) Resource distribution for the fishing task: the negative binomial distribution is characterized by a relatively low mean but a long tail, representing an environment in which most patches will have few fish (e.g., 5) but a few may have up to 30 or more. (b) Optimal switching lines for the environment with 35-s travel time (thin line) and 15-s travel time (thick line). (c) Regression lines fitted to younger and older adults observed switching points in the long and short travel time environments in Experiment 1 and (d) Experiment 2.

Participants read through onscreen instructions on how to use the touch screen to catch fish and leave patches. Additionally, participants completed an unpaid training session of 4 min to familiarize themselves with the software. This training session was identical to the later main experiment (i.e., participants experienced the same resource distribution of fish at these ponds), but the travel time was 25 s (the average of the travel times in the two experimental environments). Participants then foraged for fish for 40 min in each environment. Participants took a short break between environments. In each environment, participants would first

automatically enter a pond and could then either forage for fish or move to another pond. To switch a pond, participants had to touch a red “switch pond” button (see Figure 2, lower right side of screenshot), which led to a time delay in which a bouncing ball animation with a “Please wait!” sign was shown. Participants could sequentially explore as many ponds as desired, given the constraint of the 40-min total in each environment. Once at a pond, participants could stay as long as they wanted (without exceeding the 40-min limit) and needed to forage for fish by tapping on each fish when it appeared for a short time interval (3 s, see Figure 2). Upon tapping a fish, it would be caught and automatically moved to a resource stack which was reset when entering a new pond. Catching fish was not trivial, as fishes were somewhat camouflaged by the background.

After the main experiment, participants answered some questions about the task and completed vocabulary and speed measures. The vocabulary test consisted of 37 items which required identifying the word in a set of four pseudo-words and one word (Lehrl, 1999). The speed measure was the digit–symbol substitution subtest of the German version

Table 1. Participants’ Mean Age, Education, and Cognitive Abilities (SDs) in Experiments 1 and 2

Group	Age	Education	Vocabulary	Speed
Experiment 1 ( $N=90$ )				
Younger adults	24 (3)	16 (3)	30 (2)	60 (8)
Older adults	71 (4)	16 (4)	34 (2)	43 (9)
Experiment 2 ( $N=60$ )				
Younger adults	25 (3)	17 (3)	31 (2)	60 (8)
Older adults	70 (3)	15 (4)	32 (3)	43 (9)

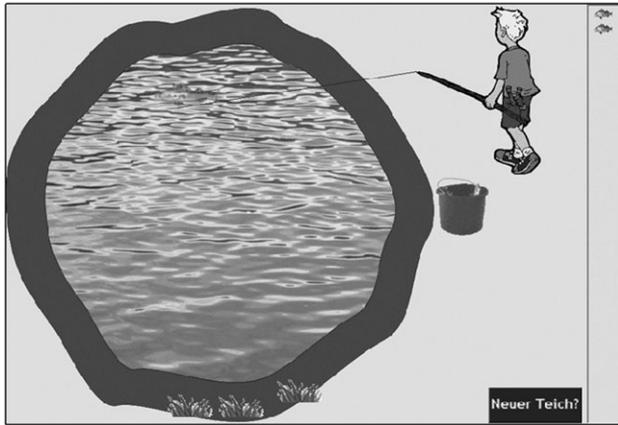


Figure 2. Screenshot of the fishing task: shows the fisherman moving the cursor toward a fish on the surface (top of pond). The resource stack (right side) shows the current foraging success, and a switching button (lower right) allows switching to a new pond.

of the Wechsler Adult Intelligence Scale–Revised (Tewes, 1991; Wechsler, 1981).

### Results

Unless otherwise noted, all dependent variables in Experiments 1 and 2 were analyzed using  $2 \times 2$  analyses of variance (ANOVAs) with the type of environment (short vs. long travel time) as the within-subject factor and age (younger vs. older) as the between-subjects factor. (The order in which participants experienced the two environments was counter-balanced and was therefore added as an additional factor. However, because order of presentation was not related to performance of either younger or older adults or other predictors, we do not report it here.)

**Overall performance.**—Table 2 summarizes participants' performance concerning (a) the number of fish caught, (b) the number of fish missed due to attentional lapses and/or motor errors, (We additionally distinguished between attentional and motor misses so as to better gauge the nature of participants' errors. For each fish occurrence, if no attempt to touch the fish was recorded before the fish disappeared, we labeled it an attentional miss. If a touch signal was recorded but out of the fish boundaries, we labeled it a motor

miss. The results indicate that a little more than half of the misses were due to motor errors for both younger and older adults ( $M=65\%$ ,  $SD=30\%$ ). Moreover, the two types of misses (attentional, motor) are significantly correlated with each other (all  $r > .40$ , all  $p < .05$ ) for the two age groups. Consequently, we use the term *misses* to refer to both attentional and motor errors), and (c) the number of ponds visited. Concerning captures, both younger and older adults caught fewer fish in the long travel time environment. However, older adults caught overall fewer fish and missed more fish when one appeared compared with younger adults. The ANOVA concerning the number of fish caught revealed an effect of environment,  $F(1, 88)=37.65$ ,  $p < .001$ ,  $\eta^2=.30$ , and an effect of age,  $F(1, 88)=14.64$ ,  $p < .001$ ,  $\eta^2=.14$ , but no interaction between age and environment,  $F(1, 88)<0.01$ ,  $p=.96$ ,  $\eta^2<.01$ . The ANOVA with the average number of misses as the dependent variable also revealed an effect of age,  $F(1, 88)=26.33$ ,  $p < .001$ ,  $\eta^2=.23$ , but no effect of environment,  $F(1, 88)=2.71$ ,  $p=.10$ ,  $\eta^2=.03$ , or an environment–age interaction,  $F(1, 88)=0.07$ ,  $p=.77$ ,  $\eta^2 < .01$ . Participants visited more ponds in the short travel time environment compared with the long travel time environment,  $F(1, 88)=32.68$ ,  $p < .001$ ,  $\eta^2=.27$ , but there was no effect of age in number of ponds visited,  $F(1, 88)=0.91$ ,  $p=.34$ ,  $\eta^2=.01$ , or an interaction between age and environment,  $F(1, 88)=0.04$ ,  $p=.84$ ,  $\eta^2<.01$ .

**Individual policies.**—We modeled participants' foraging strategies as linear regressions of time on captures (Hutchinson et al., 2008; Wilke, 2006). The regressions generated a slope and intercept for each environment for each participant, where the intercept represents the initial staying time, that is, the time the participant is willing to wait in a pond without capturing any fish, and the slope represents the increment added to the waiting time with each capture. The mean staying time and time increments for the different age groups in each environment are presented in Table 3. (We expected the slopes to be positive, thus demonstrating that the effect of a capture is to increase time spent in a patch. One alternative explanation for the positive regression slopes is that subjects spend random amounts of time in a patch regardless of their capture success. In this case, longer times spent at a pond also lead to more fish being found and, therefore, a positive relation between captures

Table 2. Participants' Mean Captures, Misses, and Ponds Visited (*SDs*) in Experiments 1 and 2

Group	Short travel time environment			Long travel time environment		
	Captures	Misses	Ponds	Captures	Misses	Ponds
Experiment 1 ( $N=90$ )						
Younger adults	86.8 (13.8)	2.2 (2.8)	13.6 (5.2)	73.5 (14.2)	1.6 (2.0)	11.0 (3.3)
Older adults	77.2 (18.2)	8.7 (9.1)	12.8 (7.0)	63.7 (16.8)	7.8 (8.2)	9.9 (4.3)
Experiment 2 ( $N=60$ )						
Younger adults	92.7 (15.0)	1.2 (2.1)	16.1 (6.4)	77.3 (12.7)	1.5 (2.5)	11.6 (3.3)
Older adults	81.3 (18.7)	9.6 (8.7)	14.7 (7.1)	68.4 (16.9)	7.1 (4.7)	11.1 (5.7)

and time. However, previous work suggests that this is not the case [Hutchinson et al., 2008]. Hutchinson and colleagues took the observed set of staying times of each subject in their experiment and simulated how many fish would be caught at a pond containing an initial number of fish randomly selected from the environments faced by that subject. They then analyzed the simulated data using an identical linear regression procedure as the real data. Hutchinson and colleagues found that the null model predicted slopes significantly less steep than real data, suggesting that their participants did increase time at a pond with each capture.) Note that in Figure 1c, the intercept refers to a point on the *x*-axis because we keep with the behavioral ecology literature tradition of presenting time on the *x*-axis (e.g., Iwasa et al., 1981).

A look at Table 3 indicates participants' mean staying times, and time increments were considerably different from the respective optimality predictions, albeit younger adults' initial staying times look closer to the optimal values. Nevertheless, participants seem to have been adaptive in that they adjusted their strategy parameters as a function of the environment. The ANOVA concerning the staying time parameter revealed an effect of environment,  $F(1, 88) = 3.91, p = .05, \eta^2 = .4$ , and an effect of age,  $F(1, 88) = 4.46, p < .04, \eta^2 = .05$ , but no interaction between age and environment,  $F(1, 88) = 1.52, p = .22, \eta^2 = .02$ . The ANOVA concerning the time increment parameter revealed no effect of environment,  $F(1, 88) = 0.48, p = .83, \eta^2 < .01$ , age,  $F(1, 88) < 0.01, p = .98, \eta^2 < .01$ , nor an interaction between age and environment,  $F(1, 88) = 0.62, p = .81, \eta^2 < .01$ . The same results are summarized visually in Figure 1c: Participants' policies did not strictly follow the optimality predictions; although the time increments seem to be of the right magnitude, both younger and older participants tended to show too long of an initial staying time, with older adults being more likely to initially wait too long for a fish. However, as predicted, participants adjusted their initial tendency to stay at a given pond as a function of environment structure. In contrast, the time increments in waiting time with each capture seem equivalent across the different environments and age groups.

**EXPERIMENT 2**

The results of Experiment 1 provide some support for the idea that age-related differences in foraging are related to differences in setting the initial staying time parameter. However, Experiment 1 did not control for the strategy used by younger and older participants, which could have led the two groups to approach the task differently and possibly rely on different strategies. Experiment 2 dealt with this limitation by applying the no-choice of strategy method (Siegler & Lemaire, 1997), which consisted of instructing participants about an optimal strategy for our foraging task—the incremental strategy. Specifically, participants were instructed about the general procedure of how to initially set a staying time and increment their staying time with each capture. Participants were then told that their goal was to find the correct parameters for the initial staying time and time increments so as to maximize the number of fish caught in each environment. In this way, we wanted to assess to what extent younger and older adults differed in their ability to find the appropriate initial staying time controlling for the strategy used.

*Method*

*Participants.*—Thirty younger adults (18 women) and 30 older adults (19 women) participated in Experiment 2 (see participants' characteristics in Table 1). The majority of younger adults were students from the Free University of Berlin and the majority of older adults were retirees recruited from the community through newspaper advertisements. The payoff schedule used was the same as in Experiment 1.

*Design and procedure.*—Experiment 2 followed closely the design and procedure of Experiment 1 with one major change: In the instruction phase of Experiment 2, participants were explicitly instructed about the incremental strategy and asked to adjust its use to the two different environments. The strategy instructions were the following:

“Please apply the following strategy for switching ponds: Determine an initial time span with which you want to stay at the pond even if no fish appears and let this time elapse. If no

Table 3. Predictions and Mean Parameter Values of Participants' Policies (SDs) in the Two Studies as a Function of Age Group and Type of Environment

Group	Short travel time environment		Long travel time environment	
	Staying time	Time increment	Staying time	Time increment
Optimality predictions				
Predictions	33.01	7.03	44.60	7.39
Experiment 1 (N=90)				
Younger adults	99.6 (61.7)	12.3 (5.4)	108.2 (48.5)	12.8 (5.4)
Older adults	122.8 (101.9)	12.60 (7.5)	159.9 (154.1)	12.6 (13.7)
Experiment 2 (N=60)				
Younger adults	73.1 (43.0)	12.8 (2.6)	90.5 (48.6)	13.5 (3.0)
Older adults	87.7 (59.9)	15.1 (7.4)	112.8 (69.3)	14.9 (7.9)

fish appears within that time span, then switch immediately to the next pond. However, if you see a fish within that time span, prolong the time span with which you originally planned on staying at the pond (by adding a little time to the remaining staying time). Repeat this step each time a fish appears. Only leave the pond when no further fish appear within this time span.”

After reading the instructions, the experimenter gave a demonstration of the strategy using an egg timer and saying: “Imagine a timer that you set in such a way as that it rings when you want to leave the pond. If a fish appears before the alarm goes off, then move the timer a bit backwards so that you remain a little longer at the pond. Move the timer backwards by the same time span each time a fish appears. When the timer rings, leave the pond.” The experimenter then asked the participant to repeat the instructions and answered any questions. The procedure was repeated if the participant expressed doubts regarding the strategy. Afterward, participants initiated the practice phase and completed the fishing task. Participants were not provided with the egg timer and were asked to put aside any devices that could be used as external timekeepers.

## RESULTS

### Overall Performance

As in Experiment 1, older adults were able to catch fewer fish overall and missed more fish compared with younger adults (Table 2): The ANOVA revealed an effect of age on captures,  $F(1, 58)=9.08, p < .001, \eta^2=.14$ . We also detected an effect of environment,  $F(1, 58)=34.81, p < .001, \eta^2=.38$ , but no interaction between age and environment,  $F(1, 58)=0.29, p=.60, \eta^2 < .01$ , suggesting that both younger and older adults caught fewer fish in the long travel time environment. The ANOVA with the average number of misses as the dependent variable also revealed an effect of age,  $F(1, 58)=36.42, p < .001, \eta^2=.39$ , and a small but not significant effect of environment,  $F(1, 58)=3.03, p=.09, \eta^2=.05$ , qualified by a significant environment–age interaction,  $F(1, 58)=4.36, p=.04, \eta^2=.07$ , reflecting older adults having made slightly more mistakes in the short travel time environment. Participants visited more ponds in the short travel time environment compared with the long travel time environment,  $F(1, 58)=56.48, p < .001, \eta^2=.49$ . However, there was neither an effect of age in number of ponds visited,  $F(1, 58)=0.46, p=.50, \eta^2 < .01$ , nor an interaction between age and environment,  $F(1, 58)=0.70, p=.41, \eta^2=.01$ .

As can be seen in Table 2, participants caught more fish in Experiment 2 compared with Experiment 1, and this seems to have been true for the two age groups. We compared performance in the two experiments using a  $2 \times 2 \times 2$  ANOVA with the type of environment (short vs. long travel time) as within-subject factor and age (younger vs. older) as well as experiment (1 vs. 2) as between-subjects factors. We

found a significant effect of experiment in overall performance,  $F(1, 146)=5.03, p=.03, \eta^2=.03$ , but no age by experiment interaction,  $F(1, 146)=0.11, p=.92, \eta^2 < .01$ , or age by environment by experiment interaction,  $F(1, 146)=0.17, p=.68, \eta^2 < .01$ . In sum, although our strategy instruction seems to have helped participants successfully forage in our fishing task, it seems to have done so equally for the two age groups.

### Individual Policies

As can be seen in Table 3, participants’ mean initial staying time and time increments were similar to those found in Experiment 1, albeit initial staying times look closer to the respective optimality predictions (see also Figure 1d). Also, participants, in particular older adults, showed considerably less individual differences in the initial staying time parameter, as reflected in smaller standard deviations in Experiment 2 compared with Experiment 1, supporting the claim that participants may have improved their performance by better adjusting the recommended strategy parameter—initial staying time. Overall, participants were adaptive in that they adjusted their initial staying time as a function of the environment. The ANOVA concerning the initial staying time revealed an effect of environment,  $F(1, 58)=10.11, p < .01, \eta^2=.15$  but a small nonsignificant effect of age,  $F(1, 58)=2.07, p=.16, \eta^2=.04$  and no interaction between age and environment,  $F(1, 58)=0.33, p=.57, \eta^2 < .01$ . The ANOVA concerning the time increment parameter revealed no effect of environment,  $F(1, 58)=0.06, p=.81, \eta^2 < .01$ , or age,  $F(1, 58)=2.34, p=.13, \eta^2=.04$ , nor an interaction between age and environment,  $F(1, 58)=0.27, p=.61, \eta^2 < .01$ . These results suggest that younger and older adults showed on average similar strategy parameters in terms of both staying time and time increments with each capture.

## DISCUSSION

Two studies investigated younger and older adults’ ability to adjust their foraging behavior as a function of task characteristics, namely the travel time between patches in a computerized fishing task. In the first experiment, participants were left to generate their own fishing strategies, whereas in the second, participants were instructed to use a foraging strategy that has been shown to produce optimal results in this task. Overall, the results suggest that both younger and older adults were able to adjust their foraging behavior, albeit not optimally, as a function of travel time between patches. Nevertheless, older adults showed poorer performances compared with younger adults even when instructed to use the optimal strategy. Also, we found age differences in initial staying time in Experiment 1 that did not control for strategy selection, but no significant age differences when participants were instructed to use the optimal strategy, thus suggesting that strategy selection accounted for some of the age differences. We note, however, that the

age differences in initial staying time parameter were of similar magnitudes in both experiments ( $\eta^2 = .05$  vs.  $\eta^2 = .04$ ) as were age differences in performance ( $\eta^2 = .14$  vs.  $\eta^2 = .14$ ). Consequently, we cannot exclude that age differences in initial staying time as well as other factors, such as motor and attentional errors (as reflected in missed captures), contributed to age differences in performance.

Previous research on how aging affects the ability to adaptively select strategies as a function of task characteristics suggests that although older adults are adaptive, they often choose inappropriate strategies for a particular situation and, consequently, show poorer performances (Dunlosky & Hertzog, 1998; Lemaire et al., 2004; Mata et al., 2007). Our results suggest that older adults may have additional problems fine-tuning the initial staying time parameter, which may contribute to overall poorer performances compared with younger adults. One interpretation of the finding that older adults set a longer initial staying time is that older adults are more conservative in their switching behavior, which is congruent with findings in other inference domains (Spaniol & Bayen, 2005). As a whole, this literature points out the limitations of the adaptivity assumption, the idea common to both the aging and the decision-making traditions that adaptivity is a major and ubiquitous aspect of human behavior (e.g., Baltes & Baltes, 1990; Gigerenzer et al., 1999; Payne et al., 1993). As a result, a major challenge for future research resides in specifying the boundary conditions for adaptive behavior.

Two main issues should be addressed in the attempt to understand the conditions that lead to adaptive behavior. First, future research should aim to discover which abilities are necessary conditions for observing adaptivity. For example, our findings suggest that the ability to learn the structure of the task is an important factor in determining adaptivity and performance. The small number of trials performed by each participant prevented us from conducting a meaningful analysis of learning; however, future studies should equate the number of patches, instead of total time, between younger and older adults and, thus, directly determine the impact of experience on performance. Long-term experience may also play a role in adaptive foraging. The majority of our participants probably had no fishing experience and so it remains an open issue whether experience in this domain could offset the deficits identified in our experiments.

Second, future work should investigate which task characteristics lead to adaptive behavior. Formal analysis of the relation between the statistical structure of environments and particular strategies suggests that qualitatively different strategies are suited for different resource distributions (Iwasa et al., 1981). Although some evidence exists that younger adults may not completely adjust their foraging behavior to some of these different distributions (Hutchinson et al., 2008; Wilke & Barrett, 2009; Wilke et al., 2009), we do not know how older adults fare in equivalent tasks. Finding out which are relevant task characteristics and whether younger and older adults are adaptive may prove easier in

real-world foraging tasks, such as looking up information online (Pirolli, 2007; White et al., 1999). Empirical studies investigating older adults' online information foraging could benefit from evaluating the application efficacy and adaptive selection of different search strategies in this domain, as well as the relation between application and selection (Siegler & Lemaire, 1995). For example, older adults may prove adaptive in the sense that they select strategies with which they make fewer application errors or may benefit from interventions that help them select the appropriate strategies given their error patterns.

Summing up, we investigated younger and older adults' adaptive foraging behavior. Our results suggest that both younger and older adults are adaptive in the sense of adjusting their foraging behavior as a function of task characteristics. Nevertheless, older adults showed overall poorer performances compared with younger adults even when instructed to use an optimal strategy.

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#### CORRESPONDENCE

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