To Go or to Stay: Age Difference in Cognitive Foraging

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Abstract

The study used the word search puzzle paradigm to investigate the cognitive foraging behavior among younger and older adults. Older adults had equivalent search performance with younger adults regardless of their decline in processing speed. Older adults tended to switch fewer times and persist longer in the patch than younger adults. Results further showed that switch behavior was based on the individual reflection of information uptake, which long exploitation in the patch of older adults could not be explained solely by general slowing but their higher tolerance of the decreasing marginal rate of gain. Overall, older adults expected to reach higher gains than younger adults before leaving the current patch. The age-dependent adaptive foraging behavior was also discussed.

Keywords: Foraging; cognitive aging; self-regulation; executive control; adaptive behavior.

Introduction

Prior research often discussed how younger and older adults worked in one assigned task in the laboratory. However, in the everyday life, people usually need to actively allocate their time in multiple tasks. Sometimes a new task can be initiated after finishing the current one, but oftentimes the tasks might be interleaving given our limited time and efforts. Therefore, people have to decide if they want to continue exploiting the current task or explore the new task. Hence, the main research question of the current research would be: when do people leave the current task?

From the perspective of evolutionary, researchers used the analogue of how animals foraging food among the patches in the wild to explain how people find the information among multiple information resources, such as the WWW (Fu & Pirolli, 2007; Pirolli & Card, 1999). There were some basic heuristics to decide patch departure in animal foraging model, such as adjusting the time in one patch based on the number of preys found or the rates of encountering a prey in one patch (Stephens & Kerbs, 1986). These suggested that foragers were often sensitive to the utility structures of the patch. For example, based on Charnov's marginal value theorem (1976) and the principles of diminishing return, people depart an information patch while the marginal rate of information gain equals to the average rate of gain of the patch. However, given the limited computational capacity of people, the adaptation to the new environment might be suboptimal due to the biased representation of the local environment (e.g., Fu, 2007; Simon, 1956). Payne, Duggan and Neth (2007) did a series of cognitive foraging experiments and suggested that the switch decision was not affected by the explicit gain of a patch. People did unnecessarily more switches during the task than optimal without monitoring the real-time change of the expected gains of the patches. Overall, people showed consistent tendency to switch while subgoal completion and spent longer time in the more rewarding patch.

The other line of research about time allocation to multiple tasks was in metacognition literature. Metcalfe (2002) proposed the idea of "Region of Proximal Learning", which learners selectively allocate their time to the materials that match with their levels of expertise. Reader and Payne (2007) also found the same pattern that more knowledgeable readers spent more time reading more difficult texts. Therefore, learners were able to allocate their time based on the difficulty of the materials. Recent review on self-paced learning suggested the connections between animal foraging model and previous findings on self-regulation (Metcalfe & Jacob, 2010). Some heuristics used in the foraging model were consistent in the metacognition research, such as the Brick-Wall principles, that learners or foragers leave the patch when the rate of gain falls off.

There was little research examining the age difference in foraging behavior. Mata, Wilke and Czienskowski (2009) showed that older adults were adaptive to the task characteristics in a fish foraging task, such as staying longer in one pond while between-ponds travel time was high. However, older adults did not perform better while adopting the optimal foraging strategy. Interestingly, older adults were often regarded as adaptive decision makers. Older adults often found or sampled less information but used simple heuristics or more knowledge-driven strategies to achieve good performance in the decision making or ill-defined information search tasks (e.g., Chin, Fu & Kannampallil, 2009; Mata & Nunes, 2010; Mata, Shooler & Rieskamp, 2007). Similarly, previous reading research also showed that older adults were successful to allocate their time to do more wrap-up to compensate for their poorer textbase processing during reading (Stine-Morrow et al., 2008). Summing up, the research questions of the current study were: (1) Do older adults adapt to the cognitive foraging tasks according to the heuristics in the foraging model? (2) When and why do younger and older adults leave the current task?

Methods

There were different innovative cognitive tasks used to examine the cognitive foraging behavior, such as scrabble task, fishing task and word search puzzle (e.g., Hills et al., in press; Mata et al., 2009; Payne et al., 2007). To reduce the individual difference in domain knowledge, we used the external search task in this study. In the external search task, participants need to search stimuli provided by the experimenters (e.g., word puzzle) instead of generating the stimuli from their own knowledge (e.g., verbal fluency task). Also, we would like to use tasks including more literacy activities with concrete counts of information gain. Therefore, we adopted the word search puzzle paradigm from the experiment 4 in Payne, Duggan and Neth (2007) with some modifications that were discussed in detail.

Word search puzzle was composed of a grid of letters (alphabets). Readers need to link letters within the nearby connecting grids from any directions to form a meaningful word. The words of a puzzle usually belong to a category, such as sea creatures or city names in the United States, which search process was mostly stimulus driven. Some word puzzles provide readers a list of words for them to find accordingly, and some do not. In our study, participants do not have any reference of the words in the puzzle but the category of the words.

Following the word search puzzle paradigm by Payne et al. (2007), participants need to search words in two puzzles and decide how long they want to stay in each puzzle. Participants are able to go back and forth between two puzzles anytime during the experiment. In analogue to the foraging model, patch density can be manipulated by the number of words in the puzzle; travel time can be manipulated by the time to switch to the other puzzle.

Participants

Twenty-four younger adults (Mean Age = 20.79, SD=2.80, Range=18~29; 21 were female) and 18 older adults (Mean Age =67.39, SD=5.62, Range= 61~78; 13 were female) were recruited from the community. All of the participants were graduated from high school. 87.5 % of younger adults and 94.4% of older adults have some or more than college education. One missing data of a younger adult was excluded due to the technical problem.

We included individual difference measures in the experiment. General vocabulary knowledge was measured by the Advanced Vocabulary Test (Ekstrom et al., 1976); processing speed was measured by the Letter Comparison Test (Salthouse, 1991). Older adults had better general vocabulary knowledge ($t(39)=-4.33$, $p<.001$) than younger adults. On the other hand, younger adults had better fluid ability than older adults ($t(39)=2.91$, $p<.01$).

Experimental Design

The experiment followed a 2X2X2 mixed factor design with two between-subject variables, age (young vs. old) and switch cost (no delay vs. 5 seconds delay) as well as the within-subject variable, task difficulty (easy vs. hard). Every participant needs to complete the same easy and hard word search puzzles in 15 minutes. Participants were assigned to the two switch-cost conditions in a counterbalance order. In addition, the order of the easy and hard puzzle presented on the screen was also counterbalanced.

Materials

The word search puzzle was composed of 20X20 letters. All of the words were in the category of fruits and vegetables. Therefore, the different performance of the easy and hard puzzle cannot be attributed to the familiarity or knowledge of the domain of the puzzles. The easy puzzle contained 45 words, and the hard puzzle contained 20 words. We adopted the materials of easy puzzle from the experiment 4 in Payne et al (2007) and substituted some words to lower the word frequency in the easy puzzle. Then we based on the word length and word frequency in the easy puzzle to create the 20-words hard puzzle. There was no difference in the log

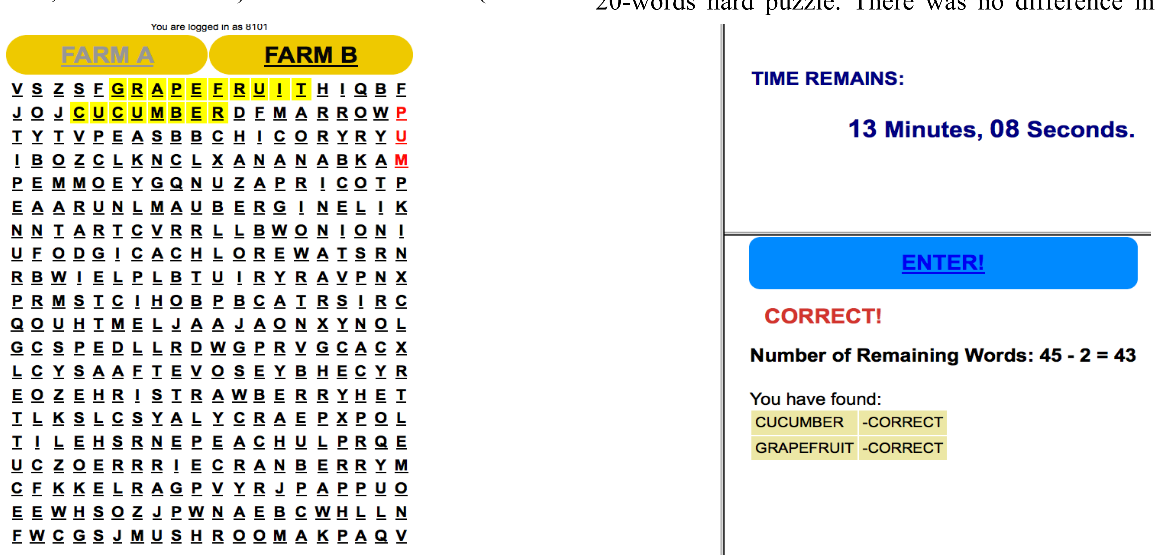

Figure 1. Layout of the word search puzzle experiments

word frequency (Balota et al., 2007, t(1,63)=0.50,p=.62) and the word length (t(1,63)=-0.24, p=.81) in the easy and hard puzzles. There were the same proportions of the words in each of the 8 different directions in easy and hard puzzles (i.e., vertical, horizontal, diagonal including both starting from upper right and upper left, as well as the reverse order for each above).

The experiment interface of word search puzzle was programmed in PhP and MySQL on an iMac computer. Participants first saw the instruction page. They could press the Start button on the screen to start the experiment. Once clicking on the Start button, participants would be taken to the world search puzzle layout (See Figure 1). At the same time, 15 minutes were counted down and shown on the upper right corner of the screen. A 20X20 gird of letters was shown on the screen. If participants find a word in the puzzle, they need to click on the letters in the correct order. To help participants keep track of their word production, the colors of the letters clicked were changed to red. After clicking on the every letter of the word, participants need to click the Enter button on the right column to submit their solution. Then the program would check if this was a real word in this puzzle and showed the results on the right column of the screen. For example, if participants clicked on G-R-A-P-E-F-R-U-I-T and clicked Enter, then they would see GRAPEFRUIT-CORRECT on the screen. Also, the program would show number of words remaining in the puzzle. Participants can refer to that information once they entered the puzzle. The words found in the task were highlighted in yellow color during the whole task.

To switch to the other puzzle, participants need to click on the button "FARM A" or "FARM B" above the puzzle. Participants were always seen "FARM A" first during the experiment. The easy or hard puzzle was assigned to FARM A in a counterbalance order. The puzzle name in the black color referred to the puzzle participants were working on; and the one in gray referred to the puzzle participants could switch to. For example, in Figure 1, if participants would like to switch to a different puzzle, they would click on the "FARM A" button. Then they would see the exactly same layout with the letters "FARM A" written in black instead. Participants assigned to the high-switch-cost condition would encounter 5-second delay while clicking on the Switch buttons. Every click on the letters, Enter button or Switch buttons was recorded with the time stamps.

Procedures

On entry to the experiments, participants completed a series of cognitive measures and a demographic questionnaire after the consent process. Then the experimenter trained the participants to do the word search puzzle study using a paper prototype. Participants had to find words from two word puzzles in 15 minutes. They can decide how long they want to spend in each puzzle. If they would like to switch to the other puzzle, they can click on the button (with the puzzle name) on the screen. Participants had been told explicitly that they could go back and forth during the experiment. They do not need to finish finding all the words of one puzzle before going to the other. They were free to decide the time they want to spend on each puzzle. The goal was to find as many words as possible. To assure the motivation of the participants, they were told if they were able to find more than 85% of the words in the puzzle, they would get $10 bonus. After the training session, participants did the word puzzle tasks on an iMac computer in a quiet room. Participants were debriefed in the end of the study.

Results

Overall Performance

A 2X2X2 Repeated Measures Analysis of Variance (Age X Switch cost X Task difficulty) showed a significant main effect of task difficulty on the number of words found in each puzzle (F(1,37)=210.66, p<.001). Both younger and older adults found more words in the easy puzzle than the hard one. There were no main effects of switch cost or age as well as other interaction effects. Therefore, both younger and older adults were able to find equally the same number of words in 15 minutes regardless of the different cost structures of the environments. Both younger and older adults were able to achieve the task goal of finding words from the word search puzzles.

Adaptation to the Task Environments

During the experiments, participants encountered two task environmental factors that might influence their decision to stay or leave the current puzzle: switch cost between puzzles and the task difficulty (i.e., expected rewards) of puzzles. Switch cost implied the travel time between patches. In the foraging model, if the travel time was long, animals tended to do more exploitation in the current patch. Task difficulty implied the expected gain of the patch, if animals expected there were more preys in the patch, they would spend longer time in the patch.

A 2X2 Analysis of Variance (Age X Switch Cost) showed the main effects of age (F(1,37)=10.10, p<.005) and switch cost (F(1,37)=4.96, p<.05) on the number of switches. Although older adults did fewer switches than younger adults during the puzzle task, both younger and older adults performed more switches in the low-switch-cost condition than the high-switch-cost condition. Therefore, both younger and older adults were adaptive to the implicit cost structure of the task.

A 2X2X2 Repeated Measures Analysis of Variance (Age X Switch cost X Task difficulty) showed main effects of age (F(1,32)=8.04, p<.01) and switch cost (F(1,32)=5.91, p<.05) on the mean duration of each visit to the puzzle. Older adults generally had longer duration on their visit to the puzzle than younger adults. In addition to the longer duration of each visit in the high-switch-cost condition, A 2X2X2 Repeated Measures Analysis of Variance (Age X Switch cost X Task difficulty) showed a main effect of switch cost on the average number of words found in each visit (F(1,37)=6.183, p<.05)), which people tended to find more words in each duration when the switch cost was high.

Table 1. Summary of data

Dependent Measure (sec: seconds)	Task	Younger Adults Mean (SD)	Older Adults Mean (SD)
Number of switches		4.7 (4.27)	1.61 (1.38)
Total number of words found		20.57 (5.38)	17.44 (6.96)
Words found in each puzzle	Easy	18.35 (5.47)	14.94 (5.96)
	Hard	2.22 (1.68)	2.5 (3.05)
Total time spent (sec)	Easy	650.70 (136.72)	643.94 (177.37)
	Hard	243.39 (142.28)	375.21 (187.50)
Mean duration of visit (sec)	Easy	320.97 (204.65)	471.5 (240.40)
	Hard	105.31 (72.78)	291.64 (217.62)
Duration of the first visit (sec)	Easy	268.25 (185.34)	649 (263.60)
	Hard	137.73 (101.22)	368 (237.89)
Number of words found in the first visit	Easy	9.92 (5.50)	14.78 (3.15)
	Hard	1.18 (0.98)	3.44 (4.00)
Mean between-item time (sec)	Easy	28.54 (6.75)	33.68 (15.52)
	Hard	27.59 (26.94)	54.69 (50.61)
Giving-up time (sec)	Easy	42.96 (28.85)	49.56 (28.71)
	Hard	66.05 (35.70)	82.44 (47.37)

Therefore, participants would like to persist longer and found more words before leaving one patch when the switch cost was high. Both younger and older adults showed this adaptation to the switch cost.

Regarding the task difficulty, we found all of the participants spent longer time (about two third of the time) in the easy puzzle than the hard one except one older adult who did not switch to the other alternative in 15 minutes. Both younger and older adults allocated more time in the easy puzzle to show their adaption to the richer patch.

Similarly, a 2X2X2 Repeated Measures Analysis of Variance (Age X Switch cost X Task difficulty) showed the main effect of task difficulty on the give-up time ($F(1, 23)=6.48$, $p<.05$). (i.e., the duration from the last word found in the current puzzle to the time switching to the other)(as in Payne et al., 2007). The give-up time was longer in the hard puzzle than the easy one.

Age Difference in Search Strategies

Although both older and younger adults showed the same adaption to the switch cost and task difficulty, they had different processing resources available due to cognitive aging. That is, older adults suffered from a decline in the fluid ability, including their processing speed and capacity of working memory, etc. We used the dependent measure, between-item time, which was used in previous study (Payne, et al., 2007), referring to the duration of finding the word. We extracted the time people entered the first letter of the correct words and labeled each first letter with a time stamp to index when people find a word. The durations between each time stamps of the first letters were the between-item time. A 2X2X2 Repeated Measures Analysis of Variance (Age X Switch cost X Task difficulty) showed the main effect of age on the between-item time ($F(1,37)=7.46$, $p<.01$). Thus, older adults need more time to find a word than younger adults.

We further fitted the cumulative time of each word production for each participant to get the parameters of their individual rate-of-gain functions. According to the Charnov's marginal value theorem (1976), optimal forager would depart the current patch when the marginal rate of gain equaled to the average rate of gain. Therefore, we regressed the cumulative time on the number of words found in each puzzle, and gained the exponents to probe the rate of gain. Given the law of diminishing return, the functions of rate of gain may not be linear. We fitted the data with linear, exponential and power functions, and found the best curve estimations for the rate of gain in each puzzle. For the easy puzzle, power functions best fit the cumulative time by the number of words found by younger and older adults. For the hard puzzle, exponential functions best fit the cumulative time by the number of words found by younger and older adults. Table 2 was a summary of the parameters we obtained from the regression models.

The exponent of each function indicated how quickly the time increased while more words were found. Therefore, participants who had bigger exponents took longer time to find a word. The exponents of the rate-of-gain functions might reflect the individual difference in cognitive foraging. First, we found age difference on the exponents in the easy puzzle ($t(38)=-2.09$, $p<.05$) which older adults had bigger exponents than younger adults. In other words, for older adults, the time to find a word increased more quickly than

Table 2. Summary of parameters in the rate-of-gain curves

	Easy Puzzle ($y=x^b$)		Hard Puzzle ($y=e^{bx}$)	
	Young (N=23)	Old (N=17)	Young (N=13)	Old (N=11)
Average Adjusted R^2 (min~max)	0.96 (.91~.99)	0.95 (.85~.98)	0.96 (.87~1.00)	0.95 (.89~1.00)
b Mean	2.37	2.55	1.66	1.84
SD	0.23	0.32	0.35	0.69
Median	2.37	2.50	1.67	1.76
SE	0.05	0.08	0.10	0.21

Note:
1. y: cumulative time; x: number of words found
2. Participants need to find more than two words in order to include in this analysis, so there were few data points excluded in the hard puzzle due to the poor performance of these participants.

younger adults. However, there was no age difference on the exponents in the hard puzzle (t(22)=-0.82, p=.42). The time to find a word in the hard puzzle increased at the same rates for both younger and older adults.

Then, we did a median split on the search performance of participants in each age group. There were four groups in the sample, younger high performers, younger low performers, older high performers, and older low performers. Performance was defined by the number of words found in the easy and hard puzzle. A 2X2 (Age X Performance) Analysis of Variance showed the main effects of age (F(1,36)=6.66, p<.05) and performance (F(1,36)=24.98. p<.001) on the exponents of the easy puzzle. Also, a 2X2 (Age X Performance) Analysis of Variance showed the main effect of performance (F(1,36)=14.12. p<.001) on the exponents of the hard puzzle. Overall, people who had smaller exponents found more words in the easy and hard puzzle.

Exponents in the easy/hard puzzle were also correlated with the between-item time (easy: r=.71, p<.001; hard: r=.47, p<.05) and the number of words participants found in the easy/hard puzzle (easy: r=-.84, p<.001; hard: r=-.72, p<.001). Then we investigated some possible factors that might influence exponents, processing speed and vocabulary knowledge of younger and older adults. We found an association between processing speed and the exponents in the easy puzzle (r=-.36, p<.05). Hence, people who had better processing speed had smaller exponents in the easy puzzle, that is, their rates of gain were higher. Then we did a median split on the vocabulary knowledge within each age group. A 2X2 (Age X Vocabulary knowledge) Analysis of Variance showed the main effects of age (F(1,36)=4.70, p<.05) and vocabulary knowledge (F(1,36)=7.26, p<.05) on the exponents of the easy puzzle. People with better vocabulary knowledge had smaller exponents in the easy puzzle, and their rates of gain were higher. Overall, we found that the rate of gain might be associated with processing speed and vocabulary knowledge, which in turn influenced the foraging patterns of participants.

Age Difference in Adaptive Strategies

Although we found that older adults became more difficult to find a new word in the easy and hard puzzle than younger adults after certain time points (e.g., 6th word in the easy puzzle as shown in Figure 2), there was no age difference in the total number of words participants found in the experiment. Therefore, older adults should adopt certain strategies to compensate for their slower rates of gain.

To answer this question, we extracted the first visit of each younger and older participant from the data to find out when they decided to leave their current patch. Half of the participants were first assigned to the easy puzzle and half of them were first assigned to the hard puzzle. We did the analysis based on the duration and the number of words found during the very first visit of the puzzle of younger and older adults. Two t-tests showed the age difference in the duration of the first visit to the easy puzzle (t(19)=-3.90, p<.001) as well as the first visit to the hard puzzle (t(19)=-2.92, p<.01). Older adults spent longer time during their first visit to the puzzle than younger adults. Also, older adults found more words during their first visit to the easy puzzle (t(19)=-2.37, p<.05) than younger adults. (There was also marginal age difference in the number of words found in the first visit to the hard puzzle (t(18)=-1.82, p=.09) which older adults found more words in the hard puzzle than younger adults.) Therefore, older adults tended to do more exploitation, spend longer time and find more words, before leaving a patch than younger adults.

General Slowing or More We found that older adults spent longer time and found more words in the first visit of the puzzle than younger adults. There might be two explanations of these tendencies: (1) older adults' long duration of the first visit and fewer switches just showed the general slowing. Younger and older adults reached the same thresholds of diminishing return when they leave the patch. They left the patch when the marginal rate of gain dropped at a similar point. However, younger adults were quicker to reach that specific marginal rate of gain than older adults. So they left the patch earlier and revisited it later to show more switches; (2) older adults' had long duration of the first visit and fewer switches because they persisted in the puzzle even if the marginal rate of gain decreasing moderately. Younger and older adults left the puzzle at different thresholds of diminishing return. In the other hand, shorter duration of the first visit of younger adults implied that they left the puzzle early when the rate of gain just dropped a little. Therefore, the age difference in number of switches and the duration of the first visit could not be explained by the general slowing due to cognitive aging solely, but the different thresholds to switch for younger and older adults instead.

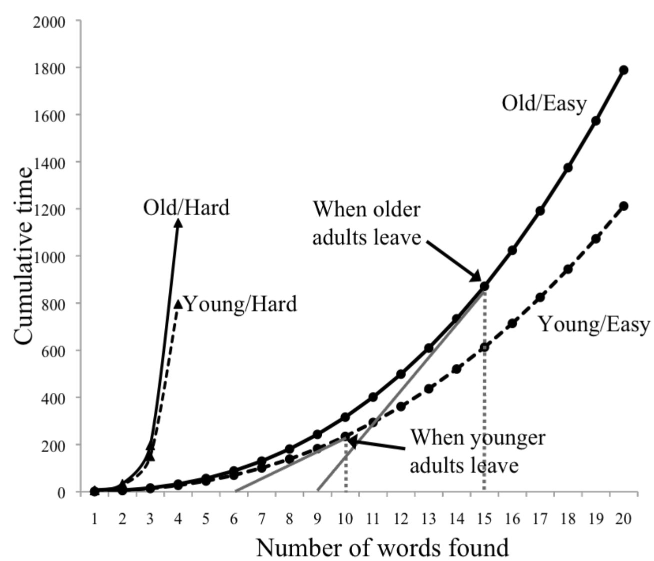

Figure 2. Rate-of-gain curve: The cumulative time of words found in easy and hard puzzle among young and old adults

To investigate the assumptions above, Figure 2 showed four rate-of-gain curves with the medians of the parameters obtained from Table 2. First, the exponents of the power functions (easy puzzle) and the exponential functions (hard puzzle) were larger for older adults than younger adults. In the easy puzzle, for the first six words of production, younger and older adults roughly showed the same rates of finding words. After the sixth word, it took more and more time for older adults to find the next word than the younger adults. The same patterns were shown in the hard puzzle.

Then, we labeled the time points when younger and older adults left the first patch. The average number of words older adults found in their first visit was 15 words, and the average number of words younger adults found in their first visit was 10 words. From Figure 2, older adults left the puzzle when the rates of gain dropped much more than younger adults. The marginal rate of gain, slope of the tangent of the curve, was steeper for older adults than the one for younger adults. Thus, we suggested that older adults had higher threshold of switch than younger adults. To achieve good performance, older adults persisted more in the current patch when the marginal rate of gain decreased.

Discussion

Our study replicated previous findings in Mata, Wilke and Czienskowski (2009) that older adults were adaptive to the characteristics of the task environments. Foragers' behavior followed the general principles of foraging theories. Both younger and older adults spent longer time in the richer patches and did more exploitation in the patch while travel time (switch cost) was high (e.g., Pirolli & Card, 1999; Stephens & Kerbs, 1986). The more intriguing finding of our study was that older and younger adults adopted different strategies to reach the same cognitive foraging performance. Older adults persisted in the patch longer while the rate of gain falling off. Older adults seemed to tolerate more when the uptake rate of the information became slower. In other words, older adults had higher threshold of switch in terms of the amount of gains they obtained. On the contrary, younger adults left the patch earlier since the marginal rate of gain slightly dropping. Younger adults were also able to do more switches and continue finding words during revisiting the same patches. Although younger and older adults left the patch at different times, they were both sensitive to the rate of gain of the tasks. The time to switch was based on their own reflection of the information uptake. This finding verified the age-dependent adaptive behavior in cognitive foraging.

Furthermore, we also found the association of the rate of gain with some basic cognitive measures, such as processing speed and general knowledge. This connection should be tested with larger sample size and more trials of foraging tasks in the future study. As Hills and his colleagues used cross-domain priming paradigm to claim the connections between central executive control and foraging mechanism (Hills, Todd & Goldstone, in press). We expected that the exponents obtained from the individual rate-of-gain curves might be a proxy of their executive control functions. For example, older adults who suffered from the decline in fluid ability (i.e., executive control) had larger exponents in the rate-of-gain curve and further influenced their departure.

In sum, we investigated the age difference in cognitive foraging behavior. Older and younger adults were both adaptive to the cost and rewarding structures of the patches. They stayed longer time in the more productive patches and in the higher-travel-time condition. However, older adults did fewer switches and persisted in the patch longer than younger adults. The higher threshold of going from exploitation to exploration for older adults helped them achieve the same good performance in the foraging task as younger adults.

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