IMPACT OF DIFFERENTIAL COGNITIVE IMPAIRMENT ON

EXPLORE-EXPLOIT DECISION-MAKING IN OLER ADULTS

By

KACIE AMANDA BAUER

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Approved by:

Dr. Robert Wilson
Department of Psychology

Abstract

In making decisions, we all must weigh the advantages of exploring new but unknown options and exploiting familiar options. For instance, when purchasing running shoes, do you explore a new brand with few but promising reviews, or do you exploit the same shoes you have used in the past and know work for you? Older adults face important explore-exploit decisions in terms of retirement savings and health treatments. Previous research on younger adults has indicated that people use two strategies to solve these explore-exploit decisions: directed exploration and random exploration. Directed exploration is guided by information-seeking, or choosing an option that will reveal more information. Low willingness to seek information denotes higher ambiguity aversion. Random exploration is guided by random decision variability, or errors in the decision process. This study uses an explore-exploit decision paradigm to measure these two types of exploration behavior in older adults. Findings indicate that cognitively impaired older adults show no random exploration, increased baseline decision noise compared to cognitively healthy older adults, and decreased directed exploration compared to cognitively healthy older adults. This suggests that older adults are making random decisions and could be missing out on favorable new options. Future research can examine how neuropsychological variables predict decision behavior, to eventually help older adults maintain their ability to make informed decisions.

Introduction

As medicine improves, more and more people are living to old age, maintaining roles in society as workers and citizens, and continuing to make important health and financial decisions. While modern medicine prolongs lives, little can be done to prevent age-related cognitive decline. So, it is critical to understand how aging affects decision-making. One specific type of decision is choosing to explore unknown options to gain information or exploit known options for a sure reward. For example, if buying sneakers, do you explore a new brand that could be promising, or exploit one you've had before that works for you? This is the explore-exploit dilemma.

Wilson et al. (2014) developed the Horizon task to measure responses to explore-exploit decision-making[1]. Their research has indicated that cognitively healthy young adults approach this dilemma with two distinct strategies: directed exploration and random exploration. Directed exploration is guided by information-seeking and involves choosing an option you know less about to reveal more information, like trying out a new brand of shoes. In this type of scenario, there may be an aversion of uncertainty, known as ambiguity aversion, that biases the chooser toward a known and familiar choice. They might just buy a new pair of the same shoes that they have been wearing, because they know those shoes are fine for them. However, the unknown choice offers an "information bonus"[2] that biases the chooser toward exploring the new pair of shoes, because it offers the advantage of gaining new knowledge. In practice, directed exploration involves a tradeoff between this ambiguity aversion and information bias.

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1 Wilson, R. C., Geana, A., White, J. M., Ludvig, E. A., & Cohen, J. D. (2014). Humans use directed and random exploration to solve the explore-exploit dilemma. Journal of Experimental Psychology: General. https://doi.org/10.1037/a0038199.

[2] Mizell, J. M., Wang, S., Frisvold, A., Alvarado, L., Farrell-Skupny, A., Keung, W., Sundman, M., Franchietti, M. K., Chou, Y., Alexander, G., and Wilson, R. C. (2020). Differential impacts of healthy aging on directed and random exploration [Unpublished manuscript]. Department of Psychology, University of Arizona.

Random exploration is guided by random decision variability, occurring when you make a noisy, unguided choice regardless of what you know about your options. It is like flipping a coin in your head to choose new shoes by chance. This randomization, or decision noise, applies to all options, so it increases the chance of choosing a low value option, enabling exploration of a choice that might have otherwise been disregarded. The decision noise in random exploration is distinct from the baseline variability that everyone has in their decisions, which indicates how random any one of their decisions might be. This often comes from cognitive load, distractions, or mistakes. In practice, it is difficult to distinguish baseline variability from random exploration.

Research has not yet investigated these strategies for explore-exploit decision-making in older adults. As the elderly population rapidly grows and must make significant choices regarding retirement, healthcare, and finances, it is increasingly important that they are making informed decisions. However, as the elderly reach older ages, they are facing more and more cognitive decline, which can affect the decision-making process. This paper investigates whether cognitive impairments in the domains of language, memory, and executive function are associated with changes in directed and/or random exploration in older adults, as compared to older adults without age-related cognitive impairment.

Methods

Participants

Fifty-nine older adults (aged 65-74) were recruited from the local Tucson community through an ad in the local newspaper. They completed the Horizon Task and a set of neuropsychological tests at the Neuroscience of Reinforcement-Learning and Decision-Making lab at the University of Arizona. All participants were screened with the Telephone Interview for Cognitive Status, and were determined free from any psychotic, neurological, or cognitivelyimpairing medical disorders. All participants gave informed consent, and the study was approved by the University of Arizona Institutional Review Board.

Neuropsychological Testing

Participants completed tasks from the National Alzheimer's Coordinating Center's (NACC) test battery[3]. This included the Montreal Cognitive Assessment (MOCA), which is a general cognitive screener[4]. Participants then completed a series of other tests that represented three cognitive domains, as identified by Bondi et al. (2014)[5]: memory, language, and executive function. These domains capture different areas of age-related cognitive impairment. Participants completed two tests within each domain. For memory, they completed Craft Story Recall Delayed (recall a story that was read earlier) and Rey Auditory Verbal Learning Test (AVLT; recall words read from a list); for language, the Multilingual Naming Task (MINT; name pictures of objects) and Category Fluency (list as many things belonging to a category as possible); and for executive function, the Trail Making Tests A (trace numbers in order) and B (trace numbers to letters, in numberical and alphabetical order)[6].

Impairment Identification

The neuropsychological test data was normed to account for age, sex, and education level, and z-scores were calculated for each participant[7]. Older adults were identified as impaired

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[3] Morris, J. C. & Kukull, W. A. (2015). Psychological Battery, Uniform Data Set v3.0 for Form C2 [Measurement Instrument]. *National Alzheimer's Coordinating Center.*

[4] Cummings, J. L., Whitehead, V., Phillips, N. A., BÃ, dirian, V., Nasreddine, Z. S., Charbonneau, S,Collin, I. (2005). The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool For Mild Cognitive Impairment. *Journal of the American Geriatrics Society*, *53*(4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.

[5] Bondi, M. W., Edmonds, E. C., Jaka, A. J., Clark, L. R., Delano-Wood, L., McDonald, C. R., Natione, D. A., Libon, D. J., Au, R., Galasko, D., and Salmon, D. P. (2014). Neuropsychological Criteria for Mild Cognitive Impairment Improves Diagnostic Precision, Biomarker Associations, and Progression Rates. *Journal of Alzheimer's Disease, 42*, 275-289. doi: 10.3233/JAD-140276.

[6] Weintraub S, Salmon D, Mercaldo N, et al. The Alzheimer's Disease Centers' Uniform Data Set (UDS): the neuropsychological test battery. Alzheimer Dis Assoc Disord, 23(2):91-101, 2009. doi: 10.1097/WAD.0b013e318191c7dd.

[7] Shirk, S. & Dodge, H. (2017). NACC UDS3 Form C2 Norms Calculator [Microsoft Excel].

if they scored outside of one standard deviation on both tests within at least one domain, or on one test within at least two domains. Fourteen participants were identified as impaired, and the other 45 as cognitively healthy.

Horizon Task

The Horizon task was developed to measure explore-exploit decision-making strategies[8]. From the task, we can model each participant's directed and random exploration, along with their baseline ambiguity aversion and decision noise. Participants are presented with two slot machines and must choose between them to earn the highest reward. The payouts are random, but one side is higher on average. The subject must learn which side has the higher mean by playing and observing the options before each choice they make.

To control the information subjects have before making a choice, each trial begins with four forced-choice plays that reveal information about the two slot machines (figure 1). There are then two manipulations that create four different conditions the participant might encounter on each trial. There first manipulation is the amount of information revealed about each slot machine: unequal information and equal information. The second manipulation is the number of choices – or the "horizon" – that the participant can make after the four forced-choice plays.

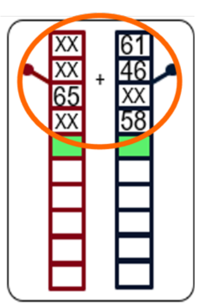


Figure 1: Horizon Task forced-choice trials.

[8] Wilson et al. (2014).

In the unequal information condition, one sample is given for one slot machine and three samples are given for the other slot machine [1 3]. In the equal condition, two samples are revealed for each slot machine [2 2] (figure 2). Participants then make free choices in one of the two horizon conditions. In the short horizon condition, they have only one choice before the game ends. In the long horizon condition, they have six choices to make (figure 3).

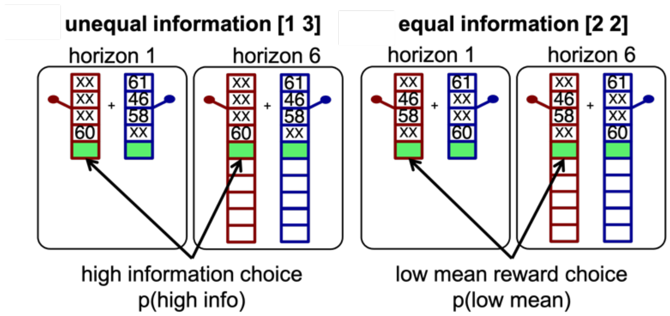


Figure 2: Horizon Task unequal and equal information conditions.

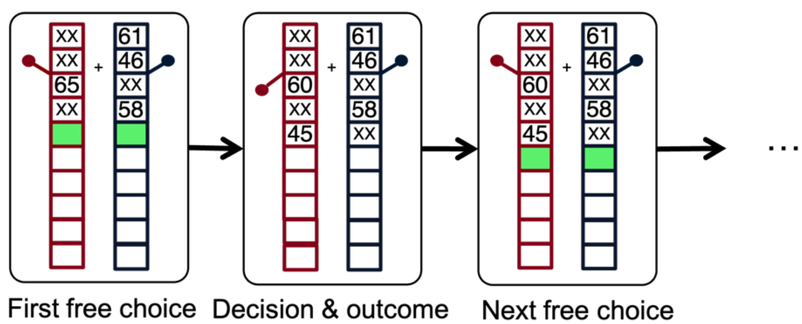
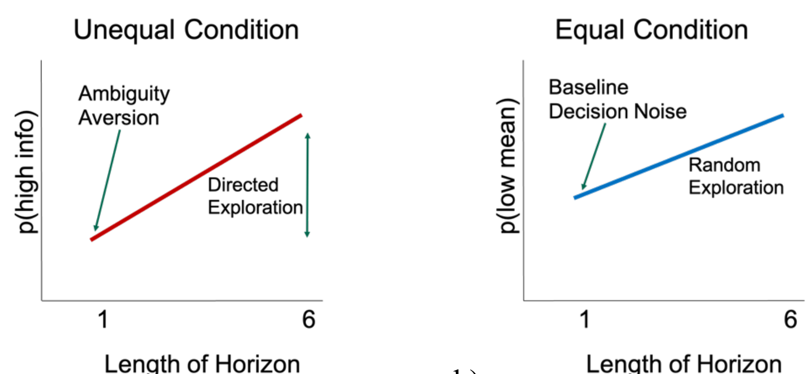


Figure 2: Horizon Task short and long horizon conditions.

In the short horizon condition, participants are expected to exploit the known-reward option, since this is their last play of the game. In the unequal information condition, the known-reward option is the slot machine with more information revealed. The participant's choice here reveals their baseline ambiguity aversion, or their preference for the known option; this is a partial measure of directed exploration. In the equal information condition, the known-reward option is the slot machine with a higher mean, based on the revealed information. A participant's choice here indicates baseline decision noise, or their tendency to choose the low-mean option by chance; this is a partial measure of random exploration.

In the long horizon condition, participants are expected to explore the low-reward options. In the unequal condition, this is the slot machine with less revealed information. This is called high-information choice, because the participant gains more information by making this choice. The probability of a participant choosing the high-information option is a partial measure of directed exploration. In the equal condition, the low-reward option is the slot machine with the lower mean, based on available information. The participant's probability of choosing the low-mean option is a partial measure of random exploration. The difference in these probabilities between the short and long horizon conditions gives the full measure of directed and random exploration (figure 4a and b).



a) b)

Figure 4: a) Directed exploration; b) Random exploration.

Results

Cognitively impaired older adults show limited directed exploration (probability of choosing the high-information option in the unequal information condition between short and long horizon conditions; $p = 0.08$), compared to cognitively healthy older adults who show significant directed exploration ($p = 0.02$) (figure 5). Impaired older adults show a non-significantly greater amount of baseline ambiguity aversion compared to healthy older adults (probability of choosing the high-information option in the unequal information, short horizon condition; $p = 0.72$).

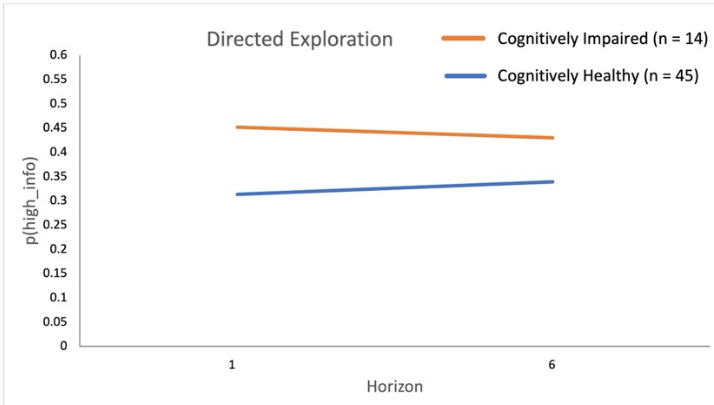


Figure 5: Directed exploration in cognitively impaired and healthy older adults.

Cognitively impaired older adults show no random exploration (probability of choosing the low-mean option in the equal information condition between short and long horizon conditions; $p = 0.31$), while cognitively healthy older adults show limited random exploration ($p = 0.09$) (figure 6). Cognitively impaired older adults have significantly greater baseline decision noise compared to cognitively healthy older adults (probability of choosing the low-mean option in the equal information, short horizon condition) $p = 0.04$), and trend toward noisier random exploration (probability of choosing the low-mean option in the equal information, long horizon condition; $p = 0.12$).

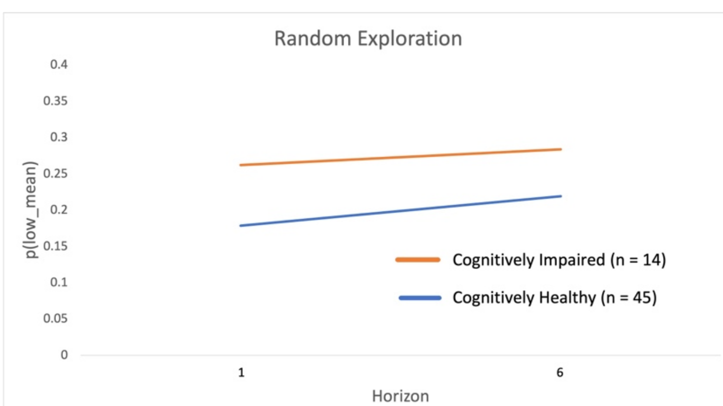


Figure 6: Random exploration in cognitively impaired and healthy older adults.

Discussion

The main finding of this study is that cognitively impaired older adults show higher baseline decision noise. This indicates that cognitive impairment in older adults may cause them to be more random in their decisions, making choices without considering their options. This has insidious implications for the important decisions older adults must make. The lack of random exploration in these impaired older adults also suggests that this decision variability remains constant through all exploratory decisions. Mizell et al. (2020)[9] demonstrate that older adults show less random exploration than younger adults, which explains the limited level of random exploration in cognitively healthy older adults. Because age-related cognitive impairment exacerbates this trend, random exploration is a key target for future research on decision-making in older adults.

The decrease in directed exploration in cognitively impaired vs. healthy older adults indicates that cognitive impairment may interfere with information-seeking. Impaired older adults are less likely to explore unfamiliar options, and instead stick with the safe choice. This means impaired older adults could be missing out on new, potentially better options, and could be exploited by the familiar options that they retain.

Only 14 older adults were identified as cognitively impaired in this dataset, which is a small sample size. More data collection needs to be done for a larger sample size that can verify or oppose these results.

Future research can explore the effects of each domain of cognitive impairment (memory, language, and executive function) on explore-exploit decision-making. Initial cluster analysis revealed differential effects of each domain, particularly executive function and memory, on

[9] Mizell et al. (2020)

decision-making behavior. More advanced analysis on larger sample sizes is necessary to determine the effects.

This and future research is important in understanding how older adults, particularly those with cognitive impairments, approach decision-making. Interventions can be designed to assist older adults in making informed decisions. For example, encouragement of careful consideration of options can compensate for a large baseline decision noise, and encouragement of exploration of unfamiliar options can increase directed exploration.

Older adults are maintaining their roles in society for longer and are making important decisions with implications for them and future generations. It is important to understand older adults' explore-exploit decision-making to foster continued informed decision-making despite any cognitive difficulties.