RATIONAL DISTRACTION: UNDERSTANDING THE ADAPTIVE NATURE OF RELIANCE ON EXTERNAL ACTION-RELEVANT INFORMATION

by

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As we age, we experience increased distractibility which has been suggested to lead to slowing of cognitive processing in older adults. Understanding the relationship between cognitive slowing and distractibility can help shed light on how humans interact with their environment across their lifespan. Is an increased dependence on external information (i.e. distractibility) a rational response to natural slowing effects of age? Based on the rational cue-checking model developed in our lab, we predict that more inspections of the environment (i.e. distractions) are relatively less costly to older adults, as their reaction times are slower. To test this, we created an eye-tracking paradigm that simulates response times between older and younger adults within a single sample of participants aged 18-35. Participants complete as many trials as they can of a cognitive task, with monetary incentive. These tasks are switched at random throughout the block, and participants must check task cues to know which task they should be following, thus simulating distractibility. To simulate the difference in response times between age groups within just younger adults, the task is manipulated to increase response time in about half of the blocks, thus replicating the age differences in reaction times. The goal is to identify if cue-checking rates increase when reaction times are slowed in individuals who have typical cognitive processing. If so, it would lead to the conclusion that the perceived distractibility of older adults may be a rational adaptation to slower cognitive processing. This research has implications for understanding those with slower cognition and adaptive behaviors they display.

Table of Contents

Introduction

As much as people try to fight it, losing mental agility is a normal part of growing older. As our intuition and empirical evidence tell us, it is common for us to decline in cognitive performance as we age. Older adults begin to suffer from a natural decline in perceptual processing which eventually manifests itself as increased distractibility (Deary, 2007). For perspective, one can imagine an older adult attempting a task such as watering plants that are located in different rooms of the house. Compared to a younger counterpart, the older adult is more likely to be drawn away from the task at hand, demonstrating predictably increased distractibility. While this may seem like a defect of cognition, it is important to look more closely at the directional relationship between cognition and distractibility. Though the common thought is that slowness in old age is caused by increased distractibility, we are investigating the possibility that the reverse is true: distractibility, the increased dependence on external information, is an adaptive trait in response to natural slowing with age.

Does cognitive slowing cause an inability to rationally orient attention or is environmental inspection an adaptive response to natural slowing effects? To test this, we have created a paradigm that simulates the attentional differences in older and younger adults within a single sample of participants aged 18-35. They are instructed to complete a cognitive computer task while an eye-tracking measures their eye position on the screen. The tasks that they are supposed to follow, however, are changed at random throughout the trial block, and the participants must occasionally check cues that tell them which task they should be following in that moment. This aspect of the experiment measures cue checking rates and simulates distractibility. To simulate the difference between individuals with lower and higher cognitive processing speeds, manipulations were done on the computer task to increase response time in about half of the trials. The goal is to see if cue checking rates increase when response time is slowed. If so, it would suggest that the distractibility of slower individuals may be rational response to slowing as opposed to being a cause slowing.

Literature Review

There has been robust evidence found, demonstrating that cognitive aging in older adults results in a slowing performance on a variety of tasks, compared to the performance of their younger counterparts. Cerella (1985) showed this through a series of studies comparing performance on information-processing tasks between elderly and college-aged subjects. Results from the study showed a slowing model that described the difference in reaction times between the two groups. The older sample had significantly slower reaction times than the college-aged participants. These results were further supported by the longitudinal study by Deary (2005), which used a within-subjects design to observe the effects of cognitive aging. Researchers analyzed data from a group that was tested at ages 16, 26, and 56 years old. Participants were instructed to complete a series of cognitive tasks. The authors reported on the variabilities and relative stability of the participants' reaction times in the tasks. This is further evidence of the declining abilities of older adults to efficiently complete simple cognitive tasks. Thus, early behavioral changes that we may observe in older adults may be attributed to their cognitive decline. The mechanisms behind these behavioral changes must be further explored, however. Though it is tempting to believe that behavioral changes are a deficit in functioning due to declining cognitive ability, it is worth exploring the potential rationale that exists innately within the individual. This can be operationalized and determined by focusing on an important behavioral deficit associated with declining response times: distractibility.

A task-switching paradigm for cognitive assessments was devised in Mayr & Liebscher (2001) to test how high executive-control demands result in differing performance corresponding with differences in age. In this experiment, the participant is relying on changing cues on the screen to determine their current task. Within the experiment, young adult participants demonstrated low fade-out costs. This means that their reaction times experienced a sharp decrease following the onset of a second phase where the task cue was changed. Older adults, on the other hand, experienced high fade-out costs, with their reaction times being persistently slow throughout the onset of the task switch. Older participants showed elevated rates of fixation on the task cues, even though intake of external cues becomes unnecessary following the onset of the second phase. The significance of this finding is that the older adults showed overall more frequent rates of cue checking. This directly relates to the perceived distractibility that we see in the elderly, where they seem to fixate on items in their environment (Thomas & Hasher, 2012). Because of social and relational factors, this type of behavior is seen as a deficit that is harmful to the individual. The purpose of our study, however, is to change this idea and provide evidence that the increased cue-checking and "distractibility" characteristics of individuals with slower response times may actually be rational.

The idea of the fade-out cost paradigms is further discussed in Mayr et al. (2015) which replicated the cue-switching task described in the previous study. Again, they reasserted the idea that older adults tend to have longer fixations and higher cue checking rates, leading to increased reaction times to the stimulus. When the cue-switching manipulation is performed, however, we see variation in the older adults' performance as their reaction times increase and their fixation on cues becomes more salient. An interesting piece of evidence is shown in the second experiment of the paper, where it is stated that the fade-out costs in older adults was eliminated completely when visually presented information was given in between the task-selection phase. This suggests that the externally displayed instructions take the place of the internally and self-generated cues that are typically seen in the response times of young adults. The paper posits that this may be due to differences between internal and external representations of task cues (*I/E balance*). Within the context of this study, we conceptualize distraction within the framework of these two sources of information. Internal representations consist of a participant's knowledge and certainty about the task are stored in memory. External representations rely on information provided to the participant in the environment, that they can refer to while completing a task. Older adults tend to have a greater reliance on external cues (distractibility) to dictate their response to a task at hand. Reliance on internally generated task representations seem to be weakened by slowing response time.

The experimental approach used in this study can be conceptualized with the example of a time-limited open-note exam. In this case, internal representations would be defined as knowledge one already has, that can be used to answer questions immediately on the exam. External representations would be notes; information that is available, but takes time to access. If one only relies on internal knowledge, more questions will be completed within the time-limit, but with uncertain accuracy. This is because one can quickly answer questions, relying on memory, without spending time checking notes. Solely relying on external information (notes) will guarantee accuracy, but performance will be slowed and fewer questions will be completed. These two extreme behaviors in the Internal (I)/External (E) balance are not optimal strategies to maximize performance on the task.

Our lab developed a Rational Cue Fixation Model (RCFM) to predict factors affecting the I/E balance. Most relevant to our hypothesis is the following equation. The model determines relative payoff differences for either checking the task cue or not, by using the calculation of a relative cue checking cost (RCC):

Equation 1:

$$RCC = \frac{RT_{checking} - RT_{not\ checking}}{RT_{not\ checking}} = \frac{t_{cue\ check}}{RT_{not\ checking}}$$

This equation shows how differing response times create varied costs for the participant. For someone with slow response times, the time cost of a single cue check is lower than for a person with faster response times. This is because slower response times means that fewer opportunities to successfully complete a task will be missed when external information is checked. Participants with fast response times experience a higher time cost every time they check a cue. In the time they take to check, they could be successfully completing more trials relative to the participant with slow response time, which means their relative cue check cost is higher.

In the present experiment, we are implementing a manipulation of difficulty to simulate slower response time for a group made up entirely of young adults. The goal is to test the prediction that increased reaction time results in a greater reliance on externally generated information. By using monetary incentive to monitor successful completion of each trial, we can monitor the cost-benefit ratio of different cue checking rates with respect to varying levels of response difficulty. We propose the following hypotheses: Slower response times, thus a lower Relative Cue-checking Cost (RCC), will lead to increased cue checking rate. Secondly, we predict that increased task switch probability will also lead to more cue checking, as task uncertainty will be taken into account when responding. Lastly, we predict that the presence of placeholders at cue locations will lead to more cue checking than when there are no placeholders. This is because there is increased bottom-up input from the environment, prompting participants to check the available information. We do not expect interactions among the variables.

This study has been preregistered within the open science framework before data analysis and is accessible under https://osf.io/dar78.

Method

Participants

Forty one University of Oregon students were recruited using the human subjects pool to participate in the study. They each received compensation in the form of research credits in addition to monetary compensation dependent on task performance.

One participant was excluded based on having response times either lower than 200 ms or in the upper 0.5%. This is done to reduce ceiling vs. floor effects, and potential resistance to experimental manipulations. The final sample consisted of 40 participants: 30 female, 8 male, with 2 subjects either choosing not to answer or identifying as another gender. The mean age was 19.7 years (*SD* = 3.08)

Stimuli

The experiment was programmed in MATLAB R2019b (The Math Works, 2019) and PsychToolbox3 (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) and executed on an Apple Mac Mini with a 24" screen. Eye-tracking was performed using the SR Research EyeLink 1000 Plus system. The study consists of 19 blocks total. The first three blocks are for practice and not included in the final data analysis. The 16 blocks that follow are the experimental portion, providing the relevant data to the study. Participants were exposed to stimuli on a computer that consisted of a two-by-two grid of white-outlined squares positioned on a blank black background. One of the four squares contains 100 dots which are moving in the same direction (Figure 1). From trial to trial, the participant must complete one of two possible tasks. The *Location* task requires that the participant indicate which of the four squares *contains* the moving dots. The second task, *Direction*, has the participant identify which one of the four squares the dots are moving *towards*. To indicate the response, the subject must use an Apple Trackpad, which serves the same function as a computer mouse, with the advantage that it remains stationary on the desk regardless of the cursor movement on-screen. The participant must drag the cursor from the center of the screen to one of four squares located outside of the central array, corresponding to each of the larger squares. After every trial, the cursor is reset to the center of the screen. The participants know which task they should do on a given trial by referencing task cues that are located above the stimuli. Each cue consists of a word (Direction or Location) and a circle. One of the corresponding circles will contain a dot; this informs the participant which task they should perform. These cues are displayed in a gaze-contingent manner. This means that the information will only be revealed when the participant moves their gaze to the top of the screen where the cues are located. The stimuli grid of squares are gaze-contingent as well; the participant must look directly at the stimulus for the moving dots to be present.

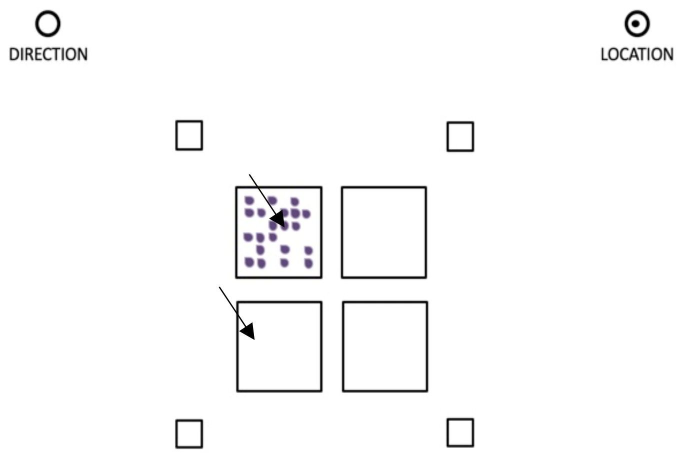


Figure 1

Example of stimuli presented to the participant. One square contains dots moving towards another square (indicated by the tail on the end of the dots). Participants indicate response by hovering cursor over the outer small squares. Cues at the top of the frame indicate which task should be completed (in this example, the "Location" task is selected, therefore the correct response is the top left outer square).

Before the beginning of each block, participants are instructed that the task may switch from trial to trial with a certain probability. For each correct trial, the participant earns $ 0.01, while losing $ 0.01 for every incorrect one. In the experimental blocks, the participants have exactly two minutes to complete as many trials as possible, with the aim of maximizing incentive earnings. The participants must make a decision regarding how often they check the task cues that ensures high accuracy but also efficiency. Every time they check a task cue, they are using time that could be spent completing more trials and earning more incentives. If they do not check the cues, though they will complete more trials, their accuracy will be low because they will not know which task to complete on a given trial. Because the task cues switch within the block, never referring to the cues would lead to frequent mistakes, thus causing them to lose incentives. If they check the cues for every trial, they will ensure high accuracy, as they will know which task to do for every trial, but will complete fewer trials within a block, thus minimizing incentives earned. This is because checking cues comes with a time cost that the participant could use to complete more trials. Therefore, there is an optimal cue-checking rate that ensures relatively high accuracy and efficiency to maximize the amount of incentives earned by the participant.

The 16 experimental blocks were fully crossed, with a response difficulty manipulation implemented to increase the participant's reaction time and test how cue-checking behavior may vary in response. The Response Difficulty manipulation slows response times to the tasks. In the high difficulty condition, the outer squares where participants select their response are smaller and farther from the center of the screen. This increases the response time by requiring the participant to span a greater distance across the screen as well as be more precise with the cursor. The low difficulty condition displayed larger outer squares that are closer to the center of the screen. This decreases the distance needed to move the cursor and does not require high precision to indicate a response. Thus, the response time is lower and the participant can complete trials faster in the low difficulty condition.

The Switch Probability manipulation concerns the probability of a task switch from trial to trial. Task switch rates of 10% and 15% were implemented to test how cue-checking behavior changes in each condition. The Placeholder manipulation put visual placeholders in the location of the task cues when the participants were looking at the stimulus. In other words, when the participant was not directing their gaze at the task cues, both circles (which would normally indicate the relevant task with a dot) were completely filled in, thus providing no information. Importantly, the dot indicating the task was revealed when the cues were inspected.

Analysis

All steps in the analysis procedure were conducted in R (R Core Team, 2021) and R Studio (R Studio Team, 2021). We employed the library *tidyverse* (Wickham et al., 2019) for analysis and result figures. The first 3 practice blocks, as well as the first ten trials of each block, were excluded from the analysis to exclude trials where participants are reorienting themselves with the task. Sixteen experimental blocks were analyzed. Additionally, trials with response times lower than 200 ms were omitted, as they suggest non-meaningful interaction with the task. Trials with response times in the upper 0.5% within each participant were also excluded.

A within-subject analysis of variance (ANOVA) was computed to test for significant effects of response difficulty, task switch probability, and placeholder presence. A paired t test and Cohen's d was computed to test for the correlational relationship between response difficulty and reaction times. Partial η_p^2 values were computed as measures of effect size.

For all analyses, the statistical threshold of $p < 0.05$ was used to determine significance.

Results

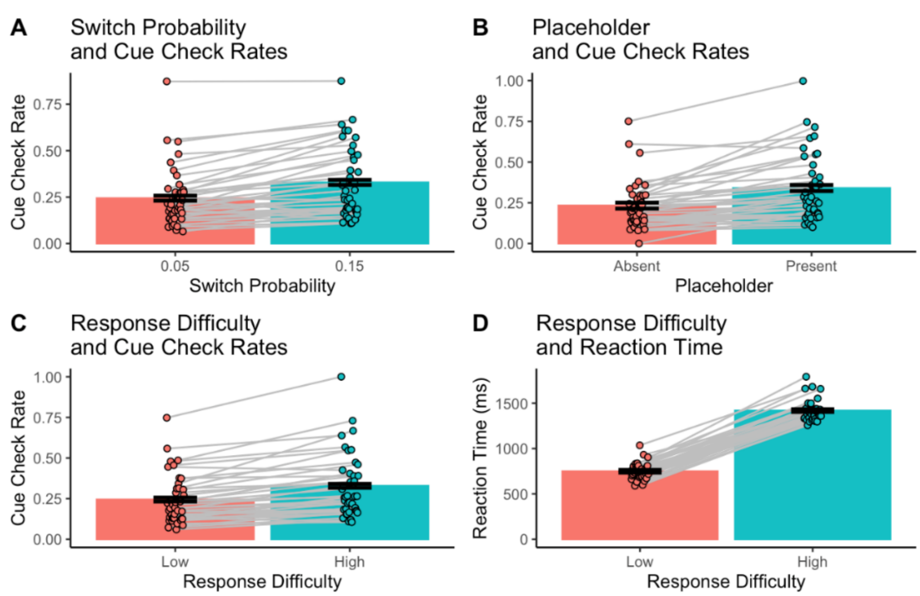
With the response difficulty manipulation, we were able to increase reaction times significantly from the easy condition ($M = 750$ ms, $SD_{within} = 45$) to the difficult condition ($M = 1419$ ms, $SD = 45$, Figure 2D). This difference was significant ($t(35) = 45.05$, $p < 0.001$, Cohen's $d = 7.61$). The main effect of response difficulty on cue-checking rates was significant $F(1, 39) = 47.98$, $p < 0.0001$, $\eta_p^2 = 0.55$). In line with our hypothesis, easy response difficulty resulted in participants checking cues at lower rates $M = 0.24$ ($SD = 0.039$), in comparison to the harder response difficulty ($M = 0.33$, $SD = 0.039$, Figure 2C). This supports our predictions, and shows how relative cue-checking cost, manipulated by response difficulty, is considered when participants increase reliance on external information.

Switch probability also showed significant ($F(1, 39) = 41.73$, $p < 0.0001$, $\eta_p^2 = 0.52$) effects, with the higher probability of 15% leading to increased cue-checking rates (*M* = 0.33, *SD* = 0.04) . The lower switch probability of 5% led to relatively decreased cue-checking (*M* = 0.24, *SD* = 0.04, Figure 2A) significantly. This supports our hypothesis, and the rational cue fixation model, as it shows that increased task uncertainty is compensated for with higher rates of cue-checking.

Placeholder effects were also shown to be significant, ($F(1, 39) = 34.92$, $p < 0.0001$, $\eta_p^2 = 0.47$), with participants increasing cue-checking rates when placeholders were present (*M* = 0.34, *SD* = 0.06), and lowering cue-checking when placeholders were absent (*M* = 0.23, *SD* = 0.06, Figure 2B). This suggests a greater reliance on bottom-up input, as the knowledge of the availability of external information increases the use of it.

Figure 2

ANOVA main effects



Discussion

In this study, we created a paradigm where participants had to weigh the use of internal and external information to guide their task performance, while trying to maximize a monetary reward. The primary goal of the experiment was to understand the rationality of increased reliance on external information in older adults. The Rational Cue Fixation Model predicts that it would be optimal to adjust cue checking rates based on the relative cost of checking the task cues, given the individual baseline reaction time. As a manipulation check, we used response difficulty manipulations, and accurately mimicked the differences in response time between older and younger adults found in previous studies (Spieler et al., 2006).

Our first finding supported our hypothesis, showing a significant relationship between response difficulty and cue checking rates. This demonstrates that participants take reaction times into account and adjust their reliance on external cues, thus maximizing their earned incentives. This is important because it supports the argument against the traditional belief that older adults, and those with slower response times, are slower because of their susceptibility to distraction by external cues (Healey et al., 2008). Instead it suggests the inverse, that increased reliance on external information may be a rational adaptation to slowing reaction times. Other studies have found a similarly beneficial relationship between distractors and slower response time (Kim et al., 2007). This study showed older adults performing better than young adults in reading tasks where distractors were present. Though the older adults were more likely to succumb to distractors, this proved useful as they were able to use the external information to exceed in later tasks. Combined with the results from our study, these findings suggest that for slower response times, an effective strategy for maximizing performance on tasks is a higher reliance on external information.

In line with our original hypothesis, higher task-switch rate significantly increased cue-checking behavior. According to the Rational Cue Fixation Model, increased uncertainty about which task is active should lead to an increased reliance on external information, as opposed to internal. With higher task switch probability, the more trials participants completed in between cue checks, the higher probability that there had been a task switch. This is exactly the pattern we observed. As the probability for a task switch increased, participants were less likely to rely on their internal representations of what task they should complete. Because of this, the participants displayed more frequent cue checking behavior to compensate for the increased uncertainty about which task to do during any given trial.

Another significant effect, in line with our hypothesis, found in our study is that cue-checking increased when placeholders were present. From a rational perspective, these placeholders should have no effect on the internal/external information balance of the participant because they were not associated with any time-related costs or benefits. What this behavior suggests is that participants' cue checking decisions are susceptible to the strength of bottom-up input. This means that the acknowledged presence of any external information is enough to prompt a cue-check, as it may prove beneficial for task performance. This leads to increased cue-checking when participants are aware of the presence of a potentially helpful cue. While we primarily investigated rational causes for differences in cue checking, these results show that irrational behavior also plays a role when individuals balance their dependence of internal versus external information.

One important limitation in the present study is that the results do not exactly mimic the aging conditions underlying causes of real-life distractibility. Though we are able to establish a strong relationship between response time and reliance on external information, we cannot accurately recreate the natural conditions that lead to increased response times in older adults. It is possible that there are underlying factors that affect response times in older adults that we are not taking account of in the present study.

The findings of this study may contribute to a greater understanding of the balance of active reliance on internal vs. external representations of knowledge. This dichotomy is especially important when applying the findings to groups of people who are more likely to have slower response times. One such population are those experiencing symptoms of ADHD, who express both distractibility and hyper focus (American Psychiatric Association, 2013). These symptoms are respectively associated with extreme reliance on external and internal information.

Our findings support the idea of a rationality behind these pathologized behaviors. This means that innate decisions made to either rely on internal or external representations of information are driven, in part, by rational variables that prove adaptable to the overall task performance. Differences in response times due to age may not be driven by increased distractibility. What our findings suggest is that increased reliance on external information is instead a rational behavior to compensate for overall cognitive slowing.

Tables

Table 1

ANOVA results

Predictor	df_{Num}	df_{Den}	SS_{Num}	SS_{Den}	F	p	η^2_g
Response Difficulty	1	39	0.57	0.46	47.98	.000	.16
Placeholder	1	39	0.93	1.04	34.92	.000	.24
Switch Probability	1	39	0.58	0.54	41.73	.000	.16
Response Difficulty x Placeholder	1	39	0.01	0.43	1.27	.266	.00
Response Difficulty x Switch Probability	1	39	0.00	0.27	0.01	.939	.00
Placeholder x Switch Probability	1	39	0.02	0.17	3.52	.068	.01
Response Difficulty x Placeholder x Switch Probability	1	39	0.00	0.06	0.02	.884	.00

Note. df_{Num} indicates degrees of freedom numerator. df_{Den} indicates degrees of freedom denominator. SS_{Num} indicates sum of squares numerator. SS_{Den} indicates sum of squares denominator. η^2_g indicates generalized eta-squared.

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