The Effect of Agency on Memory Performance in Multi-step Sequential Plan-making Using Turn-based Strategy Video Board Game

Senior Thesis submitted by

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May 2024

Abstract

This study investigates the impact of agency on memory performance using a complex, turn-based strategy game, “Into the Breach,” as a novel experimental paradigm. The research aimed to explore whether agency would enhance memory accuracy in a controlled setting that mimics real-world sequential plan-making. Participants were divided into two groups, Agency and Non-agency, to compare the effects of self-directed versus prescribed actions on memory recall. We measured absolute accuracy (accounting for order) and move accuracy (regardless of order) to assess the participants’ ability to recall sequences of actions accurately and without sequence constraints, respectively. Although participants exhibited relatively high performance on both measures, we did not observe statistically significant differences between the Agency and Non-agency conditions in either measure. These results could suggest that agency does not interact with memory for meaningful sequences, or that reducing agency has simultaneous benefits for memory processes (by reducing cognitive load and interference) as well as harms (by reducing engagement and elaboration).

Introduction

In cognitive psychology, agency is defined as the ability of individuals to make independent decisions and to exert control over their actions within their environment (Gallagher, 2000). It involves more than just the capacity to choose; the sense of agency also encompasses the individual's awareness of the potential consequences of these choices and their perceived influence over outcomes (Bandura, 2001; Moore, 2016). Agency is thus an intrinsic aspect of human behavior, enabling individuals to navigate and shape their surroundings actively.

Studying agency is crucial within the field of cognitive psychology because it directly affects how people interact with their environment, make decisions, and manage their cognitive resources. Understanding agency helps in deciphering the underpinnings of autonomous behavior and its impacts across various cognitive domains. It is particularly important because a sense of agency has been linked to better performance in cognitive tasks, greater psychological well-being, and more effective coping strategies in complex social and environmental settings (Jaegher & Froese, 2009; Tuason et al., 2021). Agency also plays a pivotal role in educational and therapeutic contexts, where different levels of agency an individual experiences can lead to variances in learning outcomes, motivation, and emotional health (Code, 2020; Taub et al., 2020; Maralov et al., 2023). By exploring the mechanisms through which agency operates, researchers can develop more effective interventions to empower individuals in their personal, social, and professional lives.

Research on agency has explored its impact across a wide range of cognitive processes, emphasizing its integral role in enhancing cognitive function. Studies have demonstrated that a

sense of agency can improve attention, problem-solving, and decision-making abilities. For instance, studies have shown that individuals can maintain items associated with a higher sense of agency more effectively in their working memory and respond more quickly in visual and attentional tasks when they experience a greater sense of agency (Zou et al., 2023; Loyola-Navarro et al., 2020). Moreover, educational research highlights that an optimal level of agency significantly boosts learning outcomes. The most effective learning occurs in moderated agency environments, where students are given enough control to remain actively engaged while guided sufficiently to maintain focus, enabling them to navigate learning resources more effectively and achieve superior educational results (Taub et al., 2020; Sawyer et al., 2017).

Focusing more narrowly on memory, the relationship between agency and memory performance has been a subject of considerable interest. Previous research suggests that agency can enhance memory by facilitating more effective encoding and retrieval processes. For example, some studies have found that agency can enhance associative memory by facilitating the binding of items in different contexts (Ruiz et al., 2023; Houser et al., 2022). Additionally, self-directed and active learning have been shown to boost memory encoding and retrieval, demonstrating advantages over passive observation (Voss et al., 2011; Markant et al., 2014). It has also been proposed that the sense of agency enhances memory by making information more self-relevant, thus benefiting from the self-reference effect in memory (Kim & Johnson, 2012). This concept is supported by recent evidence demonstrating that individuals exhibit better recall for items over which they feel a sense of agency (Hon & Yeo, 2021).

Although previous research underscores the cognitive benefits of agency, suggesting that the act of choosing itself may serve as a mnemonic enhancer, aiding in the consolidation and retrieval of memories, much of this work has been constrained to relatively simplistic experimental settings. For instance, studies like those by Hon and Yeo (2021) have primarily focused on simple decision-making tasks such as choosing the direction for visual stimuli, using simple paradigms like word list memorization and recall, where participants pressed buttons to indicate their choices, thereby linking a sense of agency directly with very basic, often binary, decisions. Similar, other studies, like those by Voss et al. (2011) and Markant et al. (2014), have allowed subjects to control their interaction with objects on a grid, determining the order and duration of their visual exploration. However, these decisions often lack meaningful context, rendering the exploration arbitrary. While these studies have successfully demonstrated the positive effects of agency under controlled conditions, their applicability to more complex, real-world scenarios remains questionable.

One aspect these studies have fallen short of demonstrating is how agency influences memory when individuals are faced with the need to remember information across plan-oriented, interconnected and prolonged tasks, during which they are expected to engage in the kind of sequential planning and strategic thinking that people commonly use in their daily lives, from navigating career decisions to managing personal relationships. This recognition of the limitations inherent in previous research points to a significant gap in our understanding of how agency affects memory performance in environments that more closely mirror the intricacies and challenges of realistic experiences, particularly those involving complex plan-making and decision-making processes. Thus, the central research question of this study emerges: How does

agency influence memory performance in multi-step sequential planning-making process? Multi-step plans require more cognitive engagement, potentially enhancing memory through deeper processing. Furthermore, planning involves accessing and exploring schemas, enriching the encoding experience and strengthening episodic memory. This dynamic interaction, which includes recalling past experiences and integrating them with future goals within a current context, helps establish multiple memory cues, improving recall efficiency and robustness. This study seeks to extend the existing body of knowledge by examining whether the cognitive benefits of agency observed in simple tasks persist, increase or even diminish in complexity when the tasks become more reflective of everyday cognitive challenges.

To address the identified research gap, this study employs "Into the Breach," a turn-based strategy video game, as a novel experimental paradigm. This game is uniquely suited to the study of agency in complex memory tasks due to its intricate design which requires players to engage in multi-step sequential planning and decision-making. Each round of play involves numerous decisions that not only have immediate consequences but also affect future outcomes, closely mimicking the complexity of real-life strategic thinking and planning. "Into the Breach" provides a more naturalistic setting than traditional memory studies, thereby offering a richer and more ecologically valid context in which to explore the cognitive effects of agency. This game-based approach allows for the manipulation of agency levels in a controlled environment while maintaining the realism of the tasks. Participants can experience varying degrees of control over their game actions—from highly directed gameplay, where moves are specified, to more autonomous gameplay, where players plan their strategies freely. This setup makes it possible to

measure how different levels of agency impact memory performance regarding both the encoding and retrieval of complex sequences and strategies.

By examining memory performance in this context, the study aims to shed light on whether the benefits of agency observed in simpler tasks extend to more demanding and realistic scenarios. It also provides an opportunity to explore how increased cognitive load, a common feature in real-life plan-making, might interact with agency to affect memory. Building on the theoretical framework and the identified need for more complex investigatory settings, this study formulates several hypotheses aimed at understanding the role of agency in memory performance in intricate scenarios. We hypothesized that participants who exercise greater agency, by creating and executing their own strategic plans in "Into the Breach," will demonstrate better memory performance than those who follow pre-determined plans. This expected improvement in memory performance could be attributed to enhanced cognitive engagement, including more effective encoding processes, increased motivation, and deeper emotional involvement with the task. Additionally, the study explores the nuances of cognitive load in relation to agency. While greater agency is presumed to enhance memory performance, an alternative hypothesis is that the increased cognitive load resulting from more complex decision-making under high agency conditions might mitigate or even reverse these potential benefits. This hypothesis addresses the possibility that while agency typically aids in memory and decision-making, its effects could be context-dependent, varying according to the task complexity and the individual's capacity to manage cognitive resources.

Methods

1. Participants

Participants for this study are being recruited from Columbia University's SONA system, which primarily draws students from the introductory Science of Psychology course, who have varying degrees of familiarity with strategic video games, with an initial recruitment of 21 participants. 5 pilot participants were only tested in agency condition and their data were not included in analysis. 2 participants demonstrated insufficient game knowledge for memory tests and were thus excluded from the data and 2 participants' data were not collected correctly due to technical issues.

In the data analysis, the sample comprised 12 participants, including 5 males and 7 females. The racial composition included 7 White participants. The age of participants ranged from 18 to 41 years, with a mean age of 22.8 years. All participants have a basic proficiency in English, along with normal or corrected-to-normal vision, to interact effectively with the game interface, and were compensated with course credits.

2. Materials

"Into the Breach" is a turn-based strategy video game that provides an ideal platform for examining complex cognitive processes including sequential plan-making. The game has been chosen for this study because of its inherent complexity and strategic depth and specific adaptations were made to ensure it is accessible and quickly learnable for all participants, regardless of their previous gaming experience.

In “Into the Breach,” players control a team of three mechs, each with unique abilities, to defend against an alien threat on a 8 x 8 grid. The version used in the study has been simplified to include only the initial group of mechs that new players typically encounter when starting the game. This group includes mechs that can perform actions including moving, dealing damage (either 1 or 2 points) and pushing enemies. These actions require players to think strategically about the sequence of their moves, considering how one mech’s actions might influence or set up the subsequent actions of the other mechs, to achieve goals cooperatively. The sequential planning inherent in managing these mechs provides a rich context for studying multi-step plan-making, where players must continuously adapt their strategies based on the dynamic game state, making decisions that have both immediate and long-term consequences on the gameplay.

To ensure that all participants, regardless of their prior gaming experience, can effectively engage with the experiment, the game has been adapted to a simplified version that focuses on basic but strategically important elements. This adaptation involves the use of 24 specific single turns, each carefully selected to align with the study’s objectives. These turns are crafted to require only a basic understanding of the game mechanics, particularly emphasizing the prevention of damage by enemies as the goal. A single turn consists of up to six steps (3 movements + 3 attacks) and has at least one perfect plan for each turn which can prevent any damage (Fig.1). Such simplification is crucial not only for reducing the learning curve but also for minimizing any disparities in game-specific knowledge among participants. By focusing on these fundamental aspects of gameplay, the experimental setup allows participants to concentrate more on strategic plan-making processes rather than on mastering complex game rules or intricate controls. This approach aims to ensure that the game sessions are both intuitive and engaging while standardizing the complexity and difficulty of the tasks across all participants,

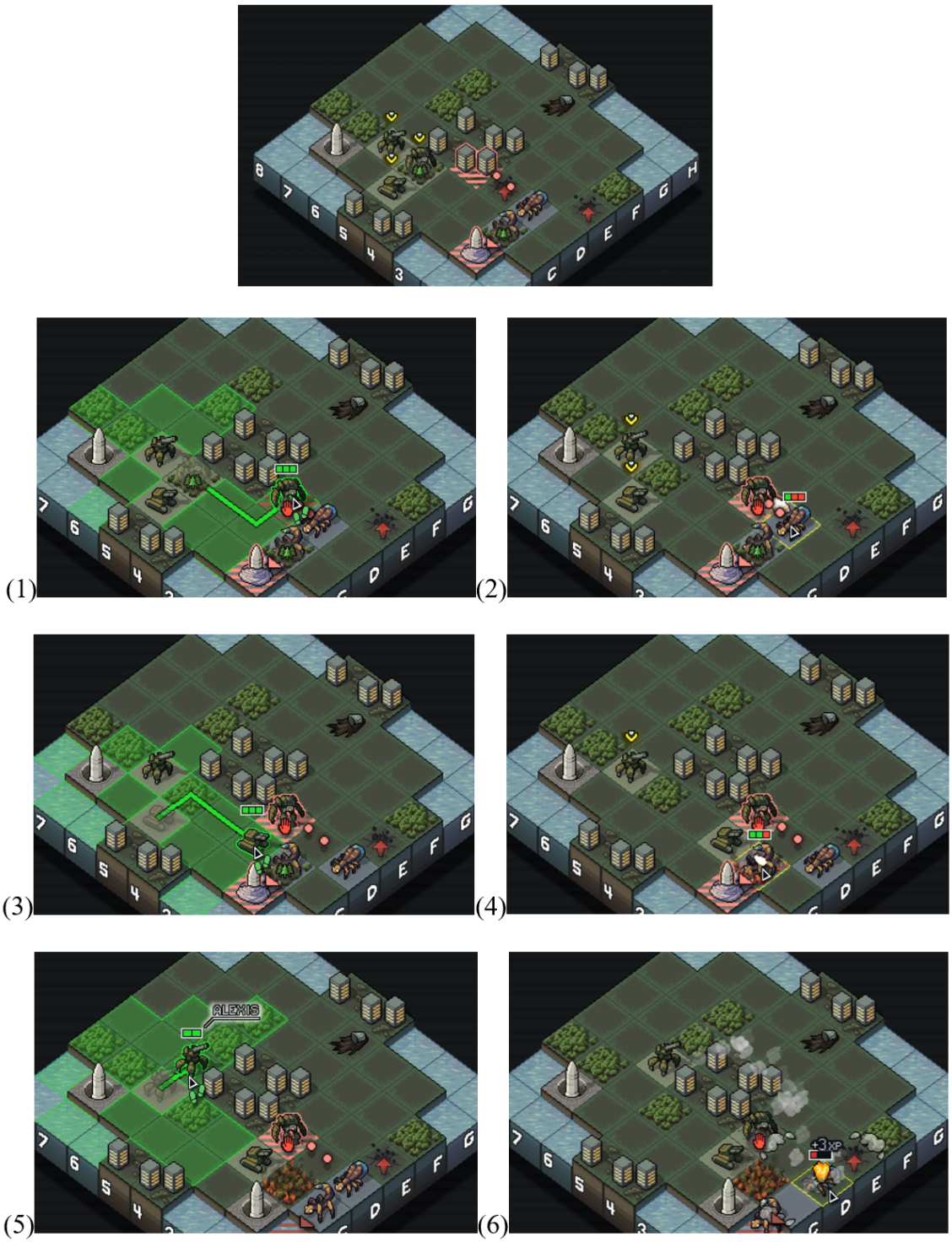

Fig.1: **Sequential Gameplay in "Into the Breach"**: A typical turn involving three mechs in the game "Into the Breach," executed over six steps to protect buildings from enemy attacks. Each panel shows one movement or attack by a mech, with the actions strategically planned to alter enemy positions and eliminate enemies. Steps are interconnected, with each movement or attack setting the stage for the next.

thus maintaining experimental consistency and ensuring that the study's focus remains on the cognitive processes of interest.

The technical setup for the experiment includes high-performance computers equipped with standard keyboards and mice to ensure uniformity in the gaming experience. NVIDIA ShadowPlay was used to record all player actions, game states, and outcomes, facilitating a comprehensive analysis of gameplay behavior.

3. Procedure

The procedure for the study is designed to allow a thorough investigation of how agency impacts memory and decision-making in complex tasks, using "Into the Breach" as the experimental platform. The experiment is conducted in two main sessions for participants to learn the game mechanics and subsequently apply strategic plan-making under different conditions of agency.

Session 1: Introduction and Familiarization (30 minutes)

Game Introduction and Practice Trial (10 minutes): Initially, participants undergo a brief tutorial session designed to introduce them to the basic rules of "Into the Breach". They went through the practice trial provided to new players by the original game with the experimenter answering and explaining any questions they raised. This tutorial focuses on explaining the distinct mechanisms of the three mechs used in the game, which include abilities including moving, dealing damage and pushing enemies. The tutorial aims to ensure that all participants start with a fundamental understanding of how to operate the game, regardless of their prior gaming experience.

Free Exploration and Practice Missions (20 minutes): Following the tutorial, participants engaged in two real missions within the game, which were not part of the experimental data collection but served to deepen their familiarity with the game mechanics. This phase allows participants to freely explore the game's interface and experiment with different strategies to accomplish different objectives. Participants were instructed not to focus on any new elements they encountered in this phase but to familiarize themselves with the operation of the game and the abilities of the mechs. The free exploration phase is crucial as it helps participants transition from understanding basic game rules to applying them in real-game scenarios, thereby ensuring they are adequately prepared for the experimental conditions in Session 2.

Session 2: Experimental Gameplay and Data Collection (60 minutes)

In the beginning of session 2, participants were asked to finish a real mission in the game to refresh their memory of the game mechanics. Participants who demonstrated sufficient game knowledge then proceeded to the task blocks, which were designed to investigate the influence of agency on memory performance through a series of interactive gameplay tasks using "Into the Breach." This session consists of eight blocks, with each block structured to include both an encoding task and a subsequent reconstruction test.

Encoding Tasks: At the beginning of each block, participants engage in three random turns of gameplay from the 24 single turns, which form the encoding tasks. In the agency condition, participants are instructed to make and execute their own strategic plans adhering to a priority list: 1) prevent the enemy from dealing any damage to the buildings, 2) prevent the enemy from

dealing any damage to any of the properties, and 3) try to kill as many enemies as possible. This condition is designed to simulate a high level of agency, where participants actively decide and implement strategies based on the game's evolving scenario. Participants are encouraged to make and execute their plan two minutes on each turn to maintain consistency and focus across the tasks.

In the non-agency condition, participants follow predetermined plans that were previously created by other participants in the agency condition. The instructions of each single move in the predetermined plans appeared on a separate window on an extended monitor at the same timing when they were executed in agency plans. This yoking design ensures that each participant in the non-agency condition is exposed to the same level of strategic complexity without the freedom to alter the course of action. This setup allows for a direct comparison between self-directed and externally guided gameplay, focusing on how these different levels of agency affect memory retention and strategic execution.

Reconstruction Tests: Following the encoding tasks in each block, participants are asked to complete a reconstruction test. In this test, they are presented with the same three turns they played during the encoding task in a randomized order. The task requires them to replicate each move exactly as they executed them in the encoding phase. This reconstruction test is critical for assessing memory accuracy and the ability to recall and perform sequential actions under different conditions of agency.

4. Data Analysis

The study employs a detailed video annotation strategy to record and assess participant actions during gameplay, including the specifics of movement, attack, and the timing of each action in "Into the Breach." Each plan executed by the participants is analyzed for the number of moves and the temporal duration, as measured by the length of the video clips. Additionally, the quality of each plan is assessed based on whether it inadvertently results in damage to the player's own properties, and whether it succeeds or fails in preventing damage to structures.

The primary quantitative analysis centers on measuring absolute accuracy, defined as the fraction of moves correctly reconstructed in the precise order they were executed. This measure reflects the participant's ability to accurately recall and sequence their actions during the reconstruction phase of the experiment. The analysis will explore whether there is a statistically significant difference in this accuracy between the agency and non-agency conditions, thus providing insights into how the level of control influences memory performance.

Further analyses include evaluating move accuracy out of order, where correct moves executed out of the intended order are still considered accurate. This secondary measure helps determine the overall memory retention of actions, regardless of their sequence under different conditions. This aspect of the analysis is crucial as it allows us to assess to what extent sequencing adds complexity to the plans and potentially impairs memory performance. Additionally, it will enable us to explore whether the impact of sequence complexity varies across conditions, providing insights into how different levels of agency might influence cognitive strategies used by participants in managing sequential information.

Fig.2: **Comparative Analysis of Absolute Accuracy vs. Move Accuracy Out of Order**: The two sequences of gameplay (upper: encoding; lower: reconstruction) in this single turn depict the same three steps executed in different orders, leading to identical outcomes of eliminating enemies. The lower sequence is considered 0% absolute accuracy as steps were reconstructed in a wrong order but 100% move accuracy when order is disregarded.

Results

Absolute Accuracy

The primary quantitative analysis focused on measuring absolute accuracy, defined as the fraction of moves correctly reconstructed in the precise order they were executed. This measure was intended to reflect the participants' ability to accurately recall and sequence their actions during the reconstruction phase of the experiment. The performance in terms of absolute accuracy is plotted in Fig.3. Given that there are many possible plans for each single turn, the random chance of replicating the same plans in reconstruction tests without relying on memory is considered extremely low. However, subjects performed well above chance level in both conditions regarding absolute accuracy (agency: mean = 0.633, SD = 0.188; non-agency: mean = 0.630, SD = 0.217). A paired t-test was conducted to explore differences, and it was found that there was no statistically significant difference in this measure of accuracy between the agency and non-agency conditions (t-value = 0.057886, df = 11, p = 0.9549, 95% CI = -0.1076743 to 0.1134910). This outcome suggests that although participants successfully used memory to retrieve their gameplay in agency and non-agency conditions, the level of agency—whether participants generated and executed their own plans or followed predetermined ones—did not substantially impact their ability to accurately recall and sequence actions.

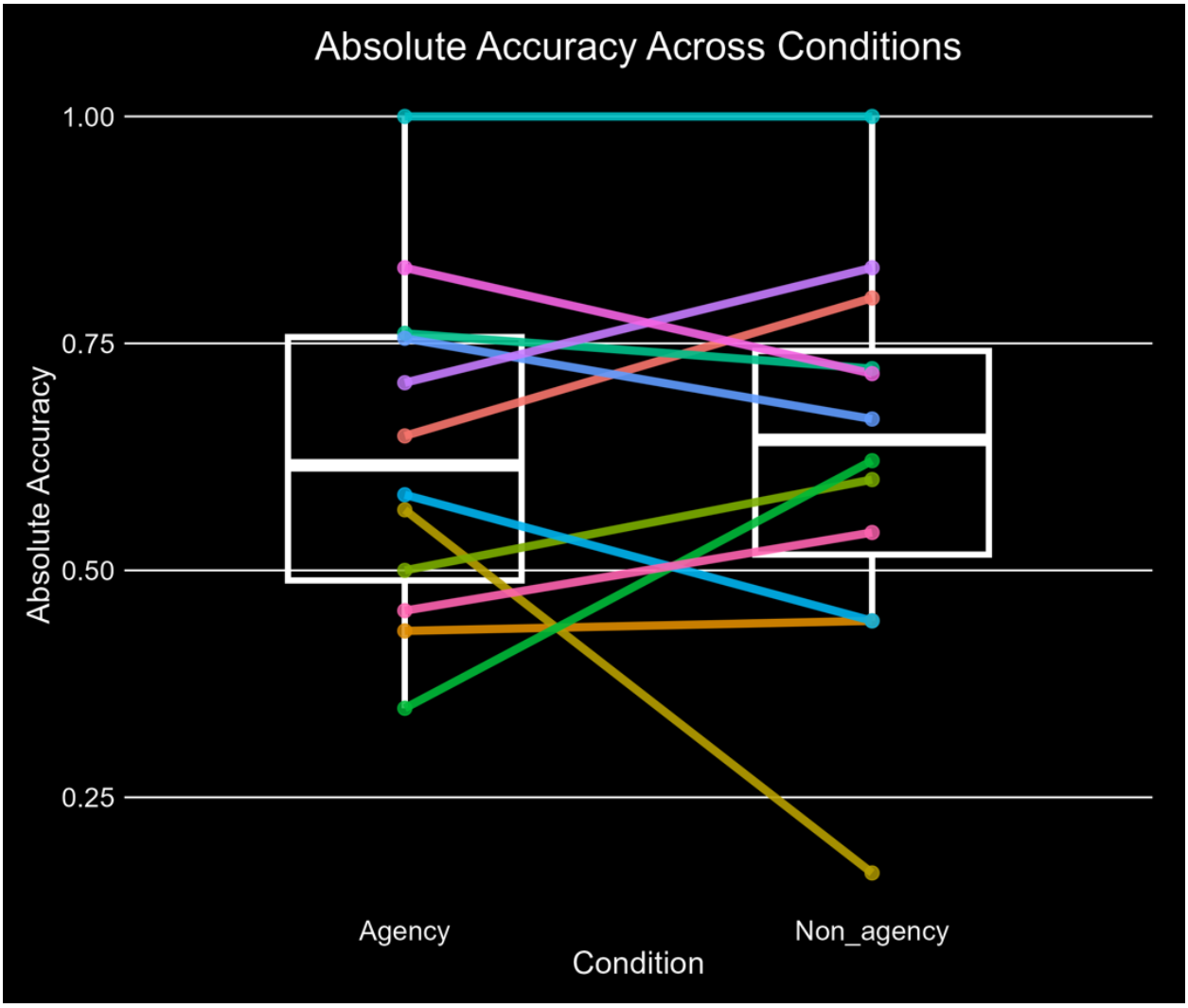

Fig.3: **Absolute Accuracy Across Conditions**: Absolute accuracy for each participant across agency and non-agency conditions, measured as the fraction of moves correctly reconstructed in their precise execution order. The box plots illustrate the range, quartiles, and median of absolute accuracy within each condition. Lines connecting data points across the two conditions represent individual performances. Despite variability in individual performances, with some participants showing improvement or decline, the overall data reveals no statistically significant difference in memory accuracy between conditions.

Move Accuracy Out of Order

To explore the potential cognitive benefits of remembering actions without the requirement to maintain their sequence, move accuracy out of order was analyzed, crediting independently correct retrieval of moves regardless of their sequence. This measure reflects the ability of participants to recall actions correctly, irrespective of the order in which they were executed. In the Agency condition, an average improvement in move accuracy out of order was noted at 0.1794083, while in the Non-agency condition, the average improvement was slightly higher at 0.185925. Employing a linear mixed model, we assessed the influence of agency on this form of memory accuracy. Although overall move accuracy showed a significant positive effect on memory performance (Fig.4; Estimate = 1.2995, SE = 0.2429, t = 5.351), indicating better memory performance in terms of action recall, the condition of agency (Estimate for Non-agency = -0.1755, SE = 0.2823, t = -0.622) did not show a significant difference. The significant improvements in move accuracy out of order in both conditions suggest that participants had greater capabilities to recall individual actions independently of their original sequence, which may imply that the cognitive demands of maintaining sequence order are robust or reflect a cognitive tendency where the recall of actions is prioritized over the sequence of those actions. However, the lack of significant difference across conditions in the measure of move accuracy out of order suggests that the level of agency did not substantially affect this ability of recalling single actions either.

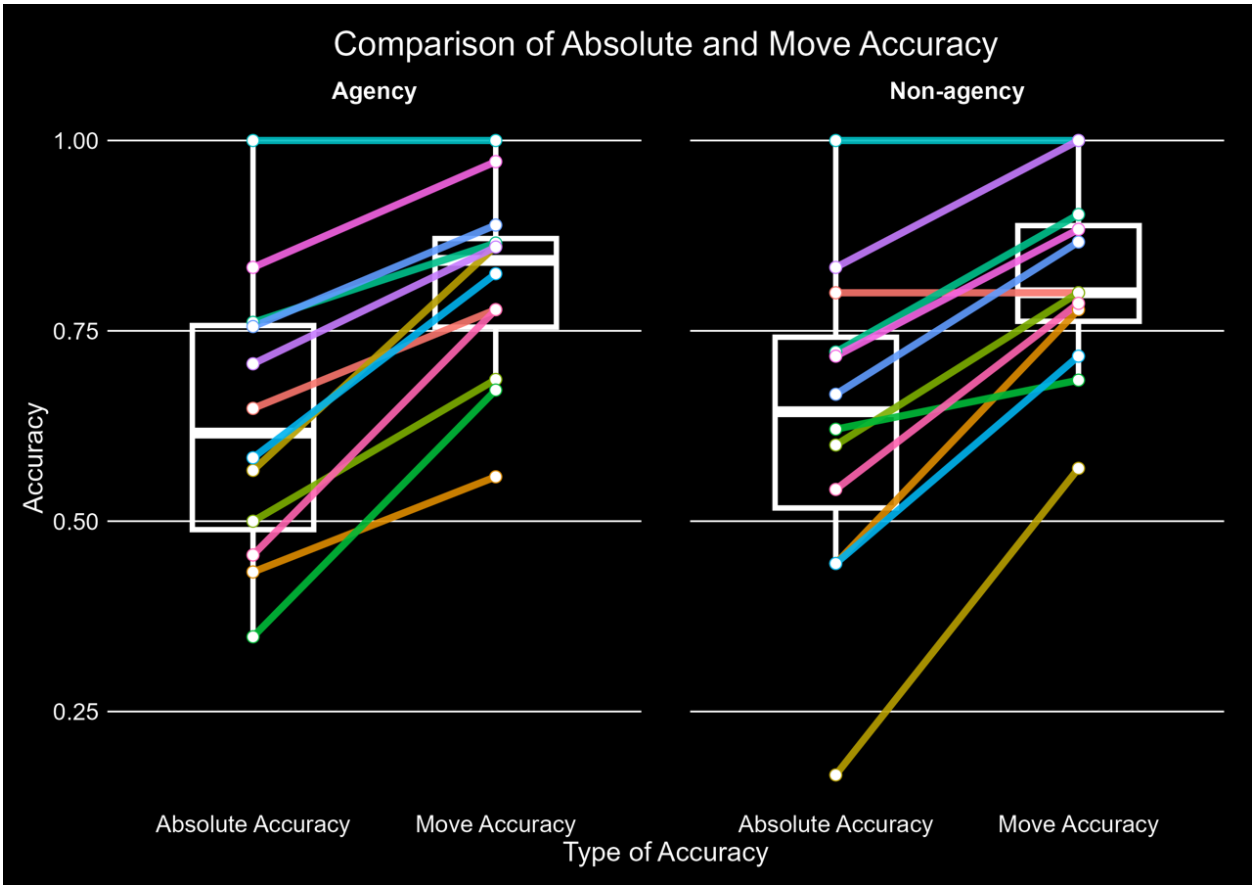

Fig.4: **Comparison of Absolute Accuracy (Accounting for Order) and Move Accuracy (Out of Order) Across Conditions**: A comparison of absolute accuracy and move accuracy out of order, measured as fraction of correctly retrieved moves regardless of order, for each participant across agency and non-agency conditions. The box plots depict the range, quartiles, and median values for each type of accuracy within each condition. Lines connecting data points between absolute and move accuracy demonstrate individual shifts in performance from structured to sequence-independent recall. Despite variations in individual performances, the overall data indicates that while move accuracy generally improves, the level of agency does not significantly influence the ability to recall actions without regard to sequence.

Discussion

This study aimed to explore the effect of agency on memory performance within the context of a complex, turn-based strategy game, “Into the Breach.” It specifically addressed the research gap concerning the role of agency on memory in multi-step sequential plan-making processes. Prior research has often demonstrated agency positively affects cognitive functions in simpler contexts where decisions are relatively straightforward and not necessarily meaningful. Our investigation sought to extend these findings to a scenario where decisions involved strategic planning and execution, aligning more closely with real-world decision-making environments.

Participants in this study displayed a level of memory performance above chance in both absolute accuracy (considering the order of actions) or move accuracy (irrespective of order), indicating their ability to finish memory tasks in this gameplay paradigm. They were able to make and remember goal-directed sequential plans and agency was manipulated successfully in this plan-making process by asking them to make their own plans or follow instructed plans. Despite this competence, no statistically significant differences were found between agency and non-agency conditions in both measures of accuracy. This result suggests that the level of agency may not significantly influence participants’ ability to accurately recall and sequence their actions in the context of the game.

These findings contribute to the broader literature on agency and cognitive processing by highlighting the complexity of how agency interacts with memory systems. While previous studies have suggested that agency enhances cognitive engagement and overall memory performance (Code, 2020; Hon & Yeo, 2021), our findings indicate that these benefits may not

universally apply to all types of memory tasks. This suggests that the cognitive benefits of agency might be context-dependent and that agency's role in enhancing memory might be limited to specific types of tasks or conditions. Specifically, in complex, real-world-like tasks such as strategic game playing, the benefits of agency might not translate into improved sequential memory performance.

One potential explanation is that agency may not exert a significant influence on memory within the specific task types employed in this study. This suggests that the distinction between participants having autonomy in creating their own plans versus following instructed plans does not impact their memory retention capabilities. Another possible explanation is that, participants in the agency condition, while actively engaged in planning and executing their moves, might experience cognitive burdens due to competing plans, which could impair the encoding process of the final selected plan. In contrast, participants in the non-agency condition, who are not burdened with strategic planning, could potentially memorize given steps more effectively. However, their lack of active engagement might diminish the depth of cognitive processing typically enhanced by personal investment and control over tasks.

This introduces an important cognitive dynamic: agency may present a trade-off between task engagement and the cognitive load it generates, potentially influencing memory performance differently based on the nature of the task. Future research should delve into finer measures of cognitive load and engagement during task performance to clarify this balance. For instance, examining the length of plans, measured by the number of steps or the temporal duration of gameplay, could indicate the cognitive load each plan imposes. Similarly, evaluating the quality

of plans, whether by errors made during gameplay or their success in achieving objectives, could shed light on the emotional resonance of each plan. Investigating these factors may reveal whether they moderate the effects of agency on memory in complex tasks.

The study's limitations, including its small sample size and the specific gaming context, might hinder the generalizability of the findings to broader populations or real-world scenarios. Future research should strive to replicate these results in more diverse and extensive samples and across varied settings to broaden the generalizability of these findings. Including participants from the gaming community could control for variations in gaming experience compared to the predominantly novice college students in this study. Moreover, exploring different types of memory tasks and varying levels of task complexity could further delineate under which conditions agency most effectively enhances memory performance. Additional investigations into the neurobiological underpinnings of how agency influences memory might enrich our understanding of the mechanisms driving these observed effects, thereby deepening our comprehension of agency's role in complex cognitive functions within decision-making tasks.

In conclusion, while agency is a critical component of cognitive and psychological theories, its role in enhancing memory, particularly sequential memory, may be more nuanced and limited than previously thought. This study suggests the need of further exploration into the intricate dynamics of agency, memory, and decision-making in complex cognitive tasks.

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