École Polytechnique Fédérale de Lausanne

Summer Research Report

Investigating the Relationship Between Sense of Agency and Episodic Memory

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"What is left over if I subtract
the fact that my arm goes up
from the fact that I raise my arm?"

— Ludwig Wittgenstein

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Abstract

School of Life Sciences (SV)
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Summer Research Report

Investigating the Relationship Between Sense of Agency and Episodic Memory

by Bruno Siniciali

Struggling to remember past events? Take control and feel agency. This research examines how the sense of agency, the feeling of controlling one's actions and their effects, relates to episodic memory, the ability to recall personal experiences in detail. My role was to implement an online experimental application to test this. While factors like sensory richness are known to influence memory, the role of the sense of agency remains unclear.

We hypothesise that greater agency strengthens the link between actions and bodily self-consciousness, the sense of being the agent of perception and movement. If an event is self-caused, one has a stronger feeling that the action "belongs" to oneself. This makes events feel more self-relevant and therefore more memorable. An associated sense of agency, which essentially offers additional information, may add a potential cue for retrieval for stimuli that have this.

In the first part of the experiment, participants are asked to move objects using a keyboard. Sometimes the object movements match the participant's input, and sometimes they do not. After each trial, the participant is asked to rate the feeling of agency they have over the object's movement. Later, they are asked to recall whether they saw the image before and its final direction.

The online version made the experiment accessible to a wider range of participants. I contributed to the experimental protocol by adding confidence questions after each recognition trial. Previous research in my laboratory found an effect on memory for object position, but not for the objects themselves. Confidence questions may help capture other aspects of this difference. Although data collection with this feature is ongoing, we expect higher agency may also influence object recognition.

Such findings would advance our understanding of self-consciousness and pave the way for non-invasive treatments for conditions like Alzheimer's and schizophrenia that imply memory and agency deficits.

Acknowledgements

During this summer, I had the privilege of meeting wonderful people. I would like to begin by thanking my fellow Laidlaw Scholars, with whom I shared an enriching and memorable summer. I am also deeply grateful to the students I worked alongside in the lab, many of whom have now become friends.

My sincere thanks go to Prof. Olaf Blanke for giving me the opportunity to join his laboratory. I would also like to thank Yannick Mijsters for his invaluable help with the implementation of the task and for making my experience in the lab as great as possible. I am grateful to Dr. Bruno Herbelin and Dr. Qiaoyue Ren for entrusting me with this exciting project and for their supervision. It would be a great pleasure for me to continue collaborating with the lab in the future.

A special thanks goes to Mattheo Yang, a fellow Laidlaw Scholar and long-time friend, for encouraging me to apply to the Laidlaw Research and Leadership Programme. Last but not least, I would like to express my gratitude to Dan Thi Nguyen and Melanie Schmidiger, whose support and trust made it possible for me to join this incredible program.

Contents

Dedicated to everyone who seeks to discover more about consciousness.

Disclaimer: This report is intended for a broad audience, but it still contains a certain number of technical terms. Please refer to the glossary if you are unfamiliar with an expression. There is a good chance its definition can be found there.

Chapter 1

Background

1.1 Introductory Example

The sense of agency is the subjective experience that emerges when individuals control their actions and external events, giving rise to the perception of responsibility for the resulting outcomes. For instance, when someone presses a button to switch on a light, it is unambiguous that they performed the action and caused the result. Yet the neural computations underlying this experience are so efficient and familiar that our sense of agency often feels minimal, almost banal.

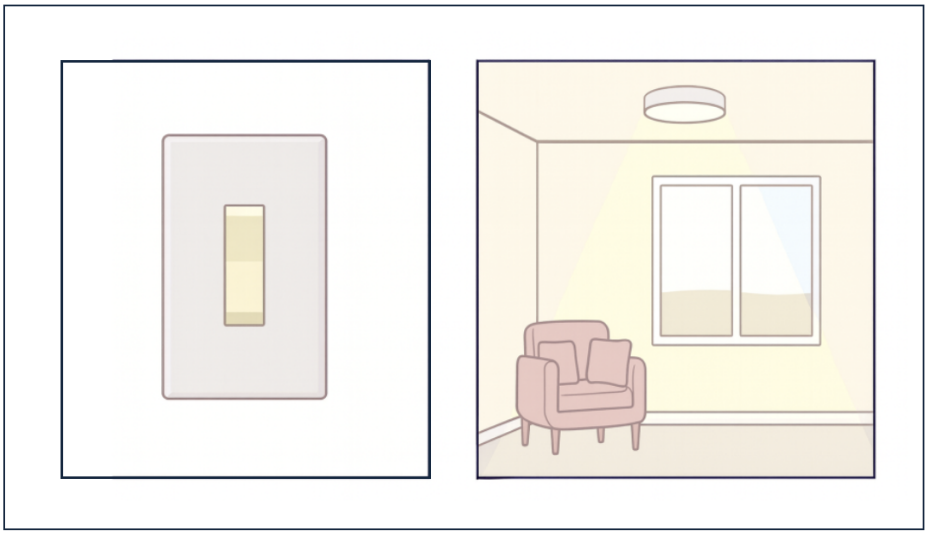

FIGURE 1.1: Introductory Example: The Light Switch

Interestingly, we tend to notice agency most strongly when it fails. This happens notably when pressing the light switch does not turn on the light. The absence of agency interrupts the normal flow of experience, drawing our attention. It makes us more conscious of what it is like to have control. On the one hand, one might expect that events marked by a lack of agency are remembered more vividly.

On the other hand, we are more likely to recall that a room's light was switched on when we pressed the switch ourselves than when it came on automatically. In this sense, memory may also be strengthened when stronger agency is present. The sense of agency is indeed closely tied to action-awareness and self-consciousness. This raises the question of whether it is surprise or familiarity that exerts the greater influence on how events are encoded and retained.

1.2 The Sense of Agency

You might have already heard about the sense of agency in relation to the Milgram Experiment (see A for more about it). At its core, the sense of agency refers to the experience of controlling one's actions and their consequences. It enables individuals to distinguish between self-generated and externally caused events. It permits to attribute the results of an action to oneself rather than to another agent. For example, if someone moves their hand because of electrical stimulation, they will not experience a sense of agency, as the action does not appear to be self-owned.

1.2.1 Mechanisms Underlying the Sense of Agency

The three key concepts underlying the sense of agency are intention, action, and effect (Wen and Imamizu, 2022). Intention refers to the desired state a person aims to achieve. The individual makes alongside a prediction about the expected effect of initiating a voluntary action. This process is also described as volition. Then comes the action, of which the person is consciously aware. Finally, the effect, which is the sensory feedback produced by the action, determines the degree of agency that is felt, reinforcing a sense of ownership over one's behavior.

From a computational perspective, the sense of agency has often been explained in terms of predictive models. The *forward model* uses an efference copy, that is, an internal copy of the motor command, to predict the sensory consequences of movements before they actually occur (Haggard, 2017). If the predicted and actual sensory feedback match, the sense of agency is reinforced; when they diverge, a prediction error arises, reducing the subjective feeling of control. By contrast, the *inverse model* works in the opposite direction: given a desired outcome, it computes the motor commands necessary to achieve that goal. In this view, agency reflects the accuracy with which intended goals can be translated into actions and their sensory consequences.

While classical accounts emphasize this sensorimotor matching process, more recent perspectives suggest that the sense of agency also depends on higher-order associations between actions and outcomes, shaped by context, expectations, and prior knowledge (Haggard, 2017).

1.2.2 Sections of the Brain Involved in the Sense of Agency

Several brain regions are implicated in the sense of agency (see 1.2). In situations associated with lower agency, stronger activity has been observed in the prefrontal cortex, more precisely, the pre-supplementary motor area (cyan), temporo-parietal junction (red), and angular gyrus of the inferior parietal lobe (green). By contrast, in situations associated with higher agency, stronger activity is found in the insula (turquoise) and the precuneus (yellow). Together, these findings suggest that the sense of agency arises from the interaction of multiple distributed regions rather than a single locus (Wen and Imamizu, 2022).

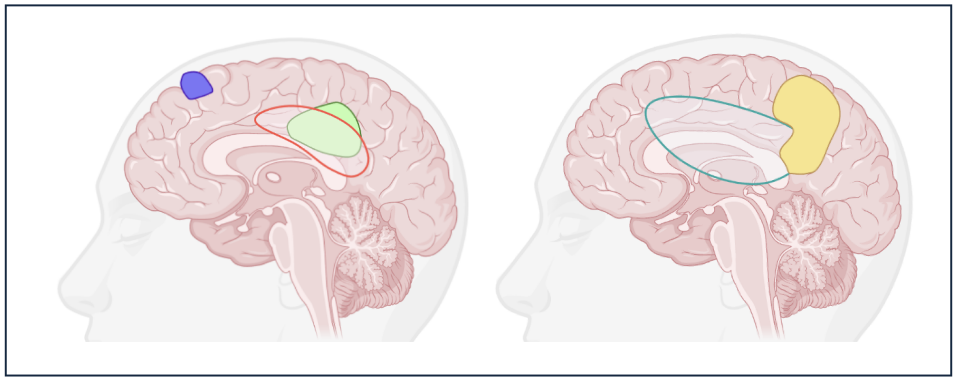

FIGURE 1.2: Brain regions implicated in the sense of agency. Left panel: regions with stronger activity in lower-agency situations. Right panel: regions with stronger activity in higher-agency situations.

If you would like to visualize where these various regions of the brain are found, I invite you to discover this website.

1.2.3 Agency as a Product of Motor Learning Circuits

Neuroscientific evidence suggests that the sense of agency is rooted in the brain's motor learning circuits, in particular the corticostriatal loops (Koralek et al., 2012). Even though the sense of agency feels like a purely psychological experience, it might in fact be built upon the same neural machinery that allows us to learn and refine movements. Even when no physical movement is involved, these motor circuits are recruited, highlighting their fundamental role in shaping our sense of agency. Importantly, this means that the human sense of agency is not a transcendental cognitive faculty, but instead emerges from the adaptive properties of brain systems underlying voluntary motor control.

The corticostriatal loops link the cortex (the "planner") with the striatum (the "action selector") and send feedback via the thalamus. The thalamus plays a crucial role as a relay and integrative hub: by channeling signals back to the cortex, it enables a continuous cycle of prediction, action selection, and feedback.

If an event is felt to be self-caused, one has a stronger feeling that the action "belongs" to oneself. This makes these events feel more self-relevant and therefore more memorable. Moreover, tasks implying higher sense of agency are intrinsically motivating and increase action readiness (Ren et al., 2023). Consequently, an associated sense of agency, which essentially offers additional information, may add a potential cue for retrieval for stimuli that have this. Thus, agency should be understood not only as a cornerstone of action control, but also as a bridge toward memory processes, underscoring its central place in human cognition.

1.3 Episodic Memory and its Encoding

1.3.1 What is Episodic Memory?

Episodic memory (EM), refers to the ability to consciously recollect personally experienced events in rich detail (Tulving, 2002). Unlike semantic memory, which encodes general facts and knowledge, episodic memory emphasizes the subjective experience of an event: how it felt, when it occurred, and where it took place. This

implies that episodic memory is not a neutral record of facts but a reconstruction of experience, which makes it particularly vulnerable to distortions influenced by internal states, emotions, and expectations.

Two processes underlie episodic retrieval: recollection and familiarity. Recollection involves consciously retrieving contextual details such as spatiotemporal features, while familiarity reflects the sense of having previously encountered an event without recalling specific details.

1.3.2 Neural Mechanisms of Episodic Memory Encoding

Episodic memory relies on a distributed large-scale network centered in the medial temporal lobe, playing a central role in binding "what, where, and when" information into cohesive memory traces (Dickerson and Eichenbaum, 2010).

Encoding is strengthened when predictions about the outcomes of actions match actual sensory feedback, leading to enhanced hippocampal encoding–retrieval similarity (Meyer et al., 2024). While occipital regions contribute to perceptual processing, they are not sufficient for core memory reinstatement. Instead, coupling between the hippocampus and motor-related regions, such as the dorsal premotor cortex, plays a crucial role in embedding agency and embodiment into episodic memory.

1.3.3 Episodic Memory as the Embodiment of Past Experiences

Episodic memory is not merely a replay of hippocampal activity but an embodied process grounded in the body's involvement at the time of encoding. For instance, reinstatement in the dorsal premotor cortex tracked hippocampal reinstatement only when the sense of agency was preserved, underscoring the link between motor representations, agency, and memory (Meyer et al., 2024). This connection suggests that episodic memory is intimately tied to selfhood, as remembering an event is shaped by how one's body participated in the experience. When actions are performed with a stronger sense of control, they feel more familiar and the corresponding events are likely more vividly recollected.

1.4 Relevance of the Experiment

Although the mechanisms that give rise to the sense of agency are well described (Haggard, 2017), much less is known about whether the experience of agency itself can influence cognition. In particular, the impact of the sense of agency on memory processes remains underexplored. One earlier study examined memory performance when participants were unexpectedly given a recognition test, suggesting that agency may modulate memory even when recall is not anticipated (Hon and Yeo, 2021). Yet systematic investigations of this relationship are still scarce.

Why are some past experiences vividly remembered while others fade? Addressing this question provides the rationale for the present experiment. The following sections first outline the experimental design, then present relevant findings from previous research conducted in the Laboratory of Cognitive Neuroscience, and finally discuss the broader significance of understanding how the sense of agency relates to memory and to everyday life.

Chapter 2

Methodology

2.1 Participants

A total of 200 healthy, right-handed adults between 18 and 33 years of age are expected to participate in the study. All participants have to report no history of neurological or psychiatric disorders, substance abuse, or use of medications affecting the nervous or muscular systems within two weeks prior to the experiment. Participants are compensated up to $50 for completing the two experimental sessions.

They are informed that they will take part in a memory task. Nevertheless, they are not informed that the main focus of the study concerns the relationship between their sense of agency and their episodic memory for the images and associated movements.

2.2 Experimental Protocol

The experiment consists of two sessions: an intentional encoding session and a retrieval session.

2.2.1 Intentional Encoding

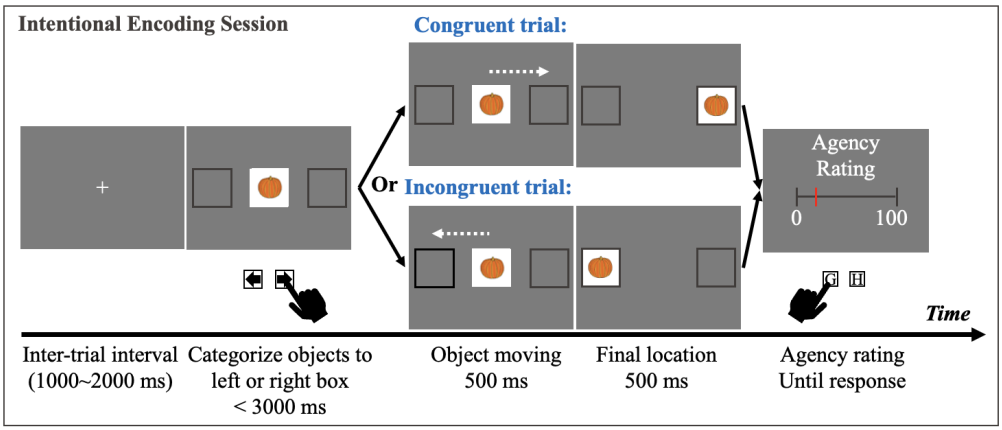

FIGURE 2.1: Task procedure during the intentional encoding session. After a fixation cross, participants categorize each object with a left or right keypress. The object then moves either congruently or incongruently with the response before remaining in its final location. Participants subsequently rate their sense of agency on a scale from 0 (no control) to 100 (full control).

In the first session, participants complete an intentional encoding task in which they view a pseudo-random sequence of 120 images. The image set consists of everyday objects (e.g., crocodile, pumpkin, rhinoceros), each presented only once. Stimuli are drawn from the Snodgrass and Vanderwart picture set and are balanced across conditions for familiarity, emotional valence, and visual complexity (Rossion and Pourtois, 2004). Images are displayed on a neutral gray background to minimize distractions. Participants are instructed to memorize the content of the images. The presentation is divided into 10 blocks of 12 images each, separated by 30-second breaks.

During the task, participants move the images across the screen by pressing with their right hand the left or right arrow key within 3000 ms. If no response is made within this time limit, a message reading "Hurry up!" appears. To reduce location bias, participants are instructed to alternate the direction of their responses. Once a choice is made, the object moves to the left or right for 500 ms, after which it remains visible for an additional 500 ms.

Two types of trials are implemented: (i) congruent trials, in which the object's motion matches the chosen arrow key, and (ii) incongruent trials, in which the object moves in the opposite direction. Each image is pre-assigned to either the congruent or incongruent condition, and this assignment varies across participants. Participants are informed about this manipulation during practice trials and are instructed to remember the final location of each image, regardless of congruency.

After each trial, participants rate their sense of agency on a continuous scale ranging from 0 (no control) to 100 (full control). They answer the question: *"How much control did you feel over the object's movement?"* by moving a cursor left or right pressing with their left hand the "G" and "H" keyboard keys, respectively.

The inter-trial interval varies randomly between 1000 and 2000 ms to reduce predictability and monotony. A fixation cross is presented to maintain participants' visual focus at the center of the screen.

The intentional encoding session lasts approximately 20 minutes in total.

2.2.2 Recognition

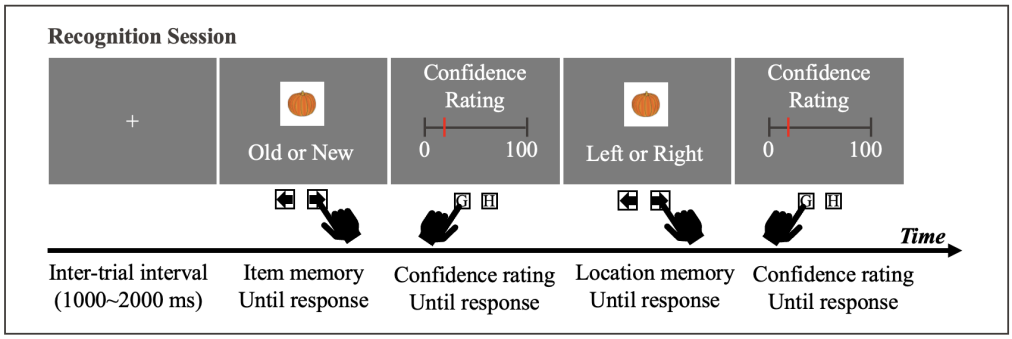

FIGURE 2.2: Task procedure during the recognition session. Participants first judge whether each image is old or new, then rate their confidence on a 0–100 scale. Next, they indicate the remembered movement direction (left or right), followed by a second confidence rating. Each trial begins with a fixation cross.

In the second session, participants complete a recognition task after a delay of either 1 hour, 3 hours, 5 hours, or 24 hours. A total of 180 images are presented, which includes 60 new images in addition to the 120 previously shown during encoding. The 200 participants are evenly assigned to the four delay groups. Images are presented in blocks of 10, and participants are allowed to take breaks between blocks.

Before starting the task, participants complete practice trials to familiarize themselves with the recognition procedure. They are then asked to provide *a priori* confidence ratings on a continuous scale from 0 (not confident at all) to 100 (fully confident). The first rating assesses confidence in remembering the content of the previously seen images, while the second rating assesses confidence in remembering the final position of the images.

During the task, each image is presented at the center of the screen. Participants are asked to indicate whether the image was previously shown in the encoding session by responding "Old" or "New" with the left or right arrow keys. After each response, participants rate their confidence in their decision using the 0–100 scale.

Next, regardless of their previous answer, participants attempt to recall the direction in which the object moved by pressing the corresponding arrow key. If they judge an image to be "New," they are instructed to answer randomly. This design allows for the possibility of analyzing implicit memory traces, as participants may have unconscious clues about image movement even when explicit recognition fails. If they respond "Old," they then provide a confidence rating for their left/right judgment.

The inter-trial interval varies randomly between 1000 and 2000 ms, during which a fixation cross is displayed at the center of the screen.

At the end of the session, participants rate whether they believe they remembered the items better when they felt greater control over the object's movement, and separately whether they remembered the object's position better under the same condition. Ratings are given on the usual 0–100 scale, where 0 indicates no perceived advantage in the congruent condition, 100 indicates better memory in the congruent condition, and 50 reflects no perceived difference between conditions.

2.3 Experimental Platform

The experiment is implemented using the JavaScript library `jsPsych`, which is specifically designed for building and running behavioral experiments in a web browser. This library is widely used in psychology, neuroscience and related fields because it allows researchers to deliver controlled experimental tasks online. Developing an online version of the experiment is particularly relevant, as it facilitates replication with different population groups. Additionally, it enables adaptation of parameters and task length for future studies.

2.4 Theoretical Rationale for Task Design

2.4.1 Direction Classification

A central feature of the paradigm is the requirement for participants to choose between two alternative actions, namely moving an image to the left or to the right. Action selection is known to strongly influence the sense of agency, as the experience of making a choice contributes to a greater subjective feeling of control (Barlas and Obhi, 2013).

The incongruent trials are designed to elicit a voluntary diminution of the sense of agency. This occurs when the predicted outcome, generated by the forward model, diverges from the actual sensory consequence of the action. An alternative method to reduce agency would have been to introduce a temporal delay between the action and its sensory consequence (Hon and Yeo, 2021).

2.4.2 Agency Rating

In the present study, the sense of agency is assessed through self-report ratings, which provide a direct and intuitive measure of participants' subjective experience. This suggests that the ratings may also be subject to certain biases (see B). Recent work has emphasized the value of more objective measures (Wen and Imamizu, 2022). A potential approach involves probing participants' sensitivity to surprise in the task. This relates to the phenomenon of sensory attenuation. It reflects a familiar experience: being touched by someone else feels more surprising than touching oneself in a deliberate and predictable way. While sensory attenuation has been proposed as an implicit index of agency, its applicability to visually mediated contexts such as the present paradigm remains unclear (Schwarz et al., 2018).

Focus: Another aspect of the agency ratings is that the way participants evaluate their sense of control over the objects' movements may be influenced by how they imagine the experiment is implemented. After a few trials, participants realize that their chosen direction does not always match the feedback. They could speculate that the outcome is pre-coded, and that the object's movement is predetermined to the left or right regardless of their choice. If so, participants might feel that they have no real agency, even in congruent trials, because they perceive the task as following a preset script rather than responding to their input. While such reasoning is unlikely to affect participants' actual choices, since most will not reflect deeply on the underlying implementation, it remains an additional consideration when interpreting agency ratings. This is partially why these ratings are based on a scale rather than a binary choice.

2.4.3 Confidence Judgments

The inclusion of confidence judgments provides an additional layer of information about participants' memory and decision-making processes. It is particularly relevant to examine how confidence ratings evolve depending on whether a trial is congruent or incongruent.

Confidence ratings often reveal systematic biases, and overconfidence has been observed in some clinical populations (Rouy et al., 2023). Thus, beyond serving as a subjective index of certainty, confidence measures allow for analyses of how individual differences in metacognitive calibration may interact with agency and memory processes.

Chapter 3

Results

3.1 Overview

The data collection using the experimental protocol described above is still ongoing. However, a similar experimental paradigm has already been conducted by Dr. Qiaoyue Ren (postdoctoral researcher at the Laboratory of Cognitive Neuroscience) and Killian Raude (EPFL Neuro-X Master's student) with a one-hour interval between the encoding and the recognition sessions. This short section presents the data they collected and the results of the analysis.

3.2 Analyses Conducted

To assess memory performance in relation to the sense of control participants experienced over the object's movement, the analyses focused on three measures: (1) **Sense of control**, or how much control participants reported feeling depending on whether the trial was congruent or incongruent; (2) **Item memory accuracy**, or how the proportion of correctly answered "Old"/"New" questions related to the sense of control; and (3) **Spatial memory accuracy**, or how the proportion of correctly answered "Left"/"Right" questions related to the sense of control.

3.3 Main Findings

3.3.1 Sense of Agency

The results indicated that the subjective sense of agency felt by the participants was higher in congruent trials compared to incongruent trials (see A.1). This confirms that the manipulation effectively altered the perceived control over the object's movement.

3.3.2 A difference between Spatial and Item Memory

Spatial memory accuracy was significantly higher in the congruent condition compared to the incongruent condition (see 3.2). In contrast, item memory accuracy remained approximately the same across both conditions.

This suggests that a stronger sense of agency boosts the binding of actions to their spatial consequences but has little effect on simple item recognition. Put differently, agency appears to enhance recollection, which is more associated with location memory, more than familiarity, which is more associated with item memory.

One possible explanation for these results is that the recognition task was "too simple." After a one-hour delay, participants were able to recognize images equally

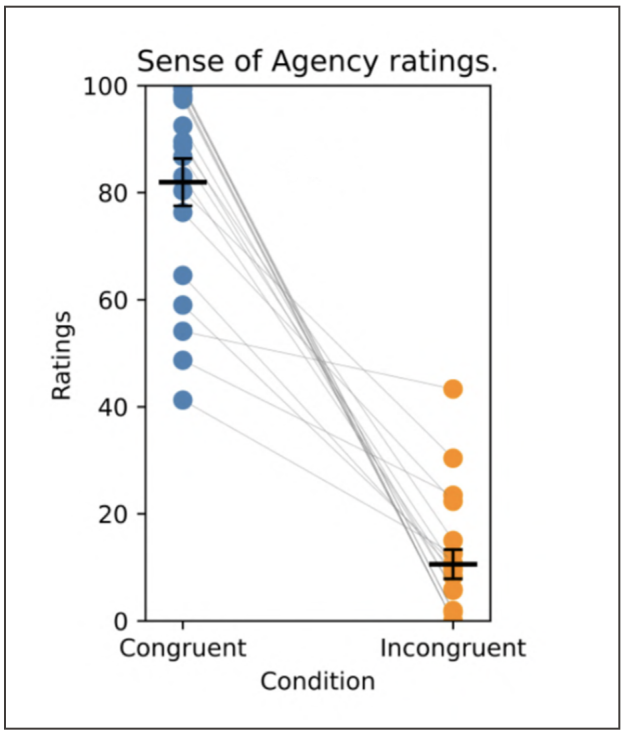

FIGURE 3.1: Sense of agency ratings as a function of trial congruency. Participants reported a higher sense of control in the congruent condition compared to the incongruent condition. Each dot represents one participant, with grey lines showing within-subject changes. Black bars indicate the mean and standard error.

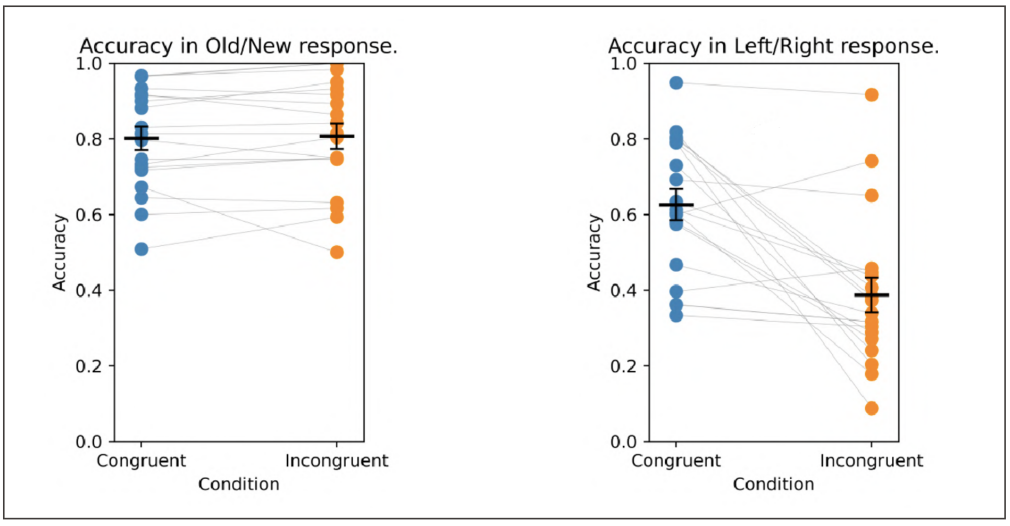

FIGURE 3.2: Accuracy in the recognition task as a function of trial congruency. **Left panel:** Proportion of correct old/new judgments (item memory). Accuracy remains similar across congruent and incongruent trials. **Right panel:** Proportion of correct left/right judgments (spatial memory). Accuracy is higher in the congruent condition compared to the incongruent condition. Each dot represents one participant, with black bars indicating the mean and standard error.

well regardless of agency, making item memory less sensitive to the manipulation. By contrast, spatial memory benefited from congruency.

These results point toward a higher action–effect binding for location memory than for item memory, suggesting that agency primarily strengthens the association of an event's consequences with the self.

3.4 Future Directions

Confidence ratings were not included in this previous experimental protocol. Adding them in the current study may provide valuable insights into how participants' subjective confidence relates to their sense of control. Such ratings could also reveal how overall confidence evolves across different retention intervals, complementing the measures of accuracy and agency.

Chapter 4

Further Discussion

4.1 Clinical Implications of Altered Sense of Agency

People are generally able to distinguish between outcomes they cause and those that occur independently of their actions. Yet, certain psychological and neurological conditions can disrupt this basic experience of control. These alterations, often described as hypoagentic states, involve a diminished, distorted, or misattributed sense of agency. Two conditions that highlight the clinical importance of studying agency will be treated in this report: schizophrenia and Alzheimer's disease.

4.1.1 Schizophrenia

Schizophrenia is associated with profound disturbances of selfhood (it is a so-called "Ich-Störung") and altered experiences of agency. Patients may report that external forces control their actions or thoughts, or conversely, they may feel responsible for events they did not cause (Voss et al., 2010). For example, patients with delusions of control may experience their thoughts and actions as being transmitted or generated by external agents rather than by themselves.

These symptoms arise from deficits in motor prediction (Wen and Imamizu, 2022). In healthy individuals, efference copies allow predicted consequences of self-generated actions to be compared with actual sensory feedback. When such predictions are missing or impaired, sensory experiences produced by one's own actions are not attenuated, and they are misattributed as external. This mismatch at a central comparator mechanism can thus explain reduced or distorted sense of agency in schizophrenia.

Beyond understanding the mechanisms, learning more about how agency relates to memory may also hold clinical relevance. If the sense of agency strengthens episodic memory encoding, then deficits in agency could help explain memory-related difficulties in schizophrenia. Following the discussions at the Laidlaw Scholars Research Symposium, the idea emerged that administering experimental paradigms such as the one described in this thesis to individuals at risk could provide valuable diagnostic clues. In addition, such approaches could offer insights for designing treatments that target both agency and memory.

4.1.2 Alzheimer's Disease

In contrast, in Alzheimer's disease the issue is not necessarily a reduced sense of agency, but rather the progressive decline in episodic memory. If future research confirms that agency enhances episodic memory, this relationship could inspire new therapeutic strategies. For example, encouraging patients to engage in activities that foster a stronger sense of agency might help support memory performance.

Although this idea remains speculative, it highlights the translational potential of agency research: what begins as a cognitive mechanism studied in healthy populations could become a practical tool for improving quality of life in clinical contexts.

4.1.3 Sense of Agency in Aging

A reduced sense of control over life events is not limited to clinical conditions but is also common in healthy older adults. With aging, people often become increasingly reliant on others, which can diminish their sense of agency and leave them feeling less in control of their lives. This reduction in agency may not only lower quality of life (Wen and Imamizu, 2022) but could also negatively affect episodic memory. Maintaining an appropriate sense of agency in older adulthood is therefore critical for overall well-being.

Preserving agency is associated with feelings of self-awareness, happiness , and self-accomplishment (Marmot et al., 1991, Frith, Blakemore, and Wolpert, 2000). Strategies to foster agency in daily life include encouraging engagement in self-chosen goals rather than imposed ones, and reinforcing autonomy in everyday activities. This can for instance consist of continuing to cook independently or at least retaining the choice of what to eat. Other activities that strengthen the link between action, effort, and outcome include writing a personal journal, rearranging one's room, planning small projects such as garden renovations, or engaging in problem-solving tasks such as crosswords and sudoku.

Learning and mastering new subjects can also increase agency and as acquired skills gradually become integrated into the self and are thus more likely to be remembered. Ultimately, the challenge lies in better integrating one's environment with one's sense of self, so that surroundings feel not only familiar but also reflective of personal identity. Such practices may help preserve both the sense of agency and cognitive function. In turn, they can support quality of life not only in older adults but across the lifespan.

4.2 Human–Machine Interaction

The rapid development of human–machine interaction technologies has created both opportunities and challenges for understanding the sense of agency. Prostheses, robotic assistance, and digital tools are increasingly designed to facilitate the accomplishment of tasks. They often involve joint control between human and machine. A central challenge, therefore, is to design interactions that minimize loss of agency that could be due to discrepancies or delay between the intended control and the execution of the action Wen and Imamizu, 2022. Reduced sense of agency may not only impair performance but, if the results of the present experiment are confirmed, could also weaken memory formation.

4.2.1 Shared Control and Its Consequences

When automation overrides or unpredictably alters user commands, individuals may feel less in control of their actions. This reduction is particularly critical in high-stakes domains such as surgery, where a lesser sense of agency can directly influence task performance. Similar risks arise in intellectual tasks increasingly supported by artificial intelligence, where automation may weaken the link between actions and outcomes. If diminished sense of agency contributes to weaker episodic memory

encoding, then the design of shared control systems becomes not only a matter of efficiency but also of cognitive integrity.

4.2.2 Training and Design Strategies

To address these issues, systems and training protocols must aim to preserve and strengthen sense of agency. Training with prosthetics, for example, should encourage corticostriatal learning (see 1) rather than relying solely on automation. More broadly, predictability and user involvement in machine responses are essential for fostering a strong sense of control. As Wittgenstein asked: *"What is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?"*. This highlights the importance of experiencing oneself as the true origin of action, which extends to the design of human–machine systems.

Chapter 5

Conclusion

5.1 Agency and Memory

It was found that a higher sense of agency enhanced recollection of the spatial location of objects, indicating that it influenced memory for the final positions of objects after they were moved. This suggests that the sense of agency does affect episodic memory, particularly by strengthening memory for the consequences of actions. However, further research is needed to better understand the mechanisms underlying this enhancement. The addition of confidence judgments and the introduction of variable time intervals will provide further insight into the extent to which the sense of agency influences both item and spatial memory. I look forward to analyzing future data incorporating these new features. If consistent results are obtained, an important next step will be to include participants from different age groups and clinical populations, in order to examine how cognitive differences shape the effect of agency on the encoding and retrieval of episodic memory. The most rewarding outcome of this research would be to contribute to the development of new approaches for diagnosing or treating neuropathological diseases, as well as for supporting memory maintenance in the elderly. Finally, these findings could also provide valuable guidance for the effective and optimized use of human–machine interaction interfaces.

The main message of my research is to take control over one's actions. If a person engages in activities that strengthen their sense of agency, they are more likely to remember what exactly happened. This connects to this year's Laidlaw Scholars conference theme, "Brave". Indeed, such control requires bravery because it involves breaking away from automatic, comfortable tasks. This shows that bravery not only brings social recognition but also leads to a higher sense of agency, which in turn enhances self-fulfillment and episodic memory.

The big question remains: does having a greater overall sense of agency improve memory in general, or are only events experienced with heightened agency remembered more vividly?

5.2 Final words and personal reflections

My experience during this summer at the lab was fascinating. I developed a passion for designing psychological tasks that help to uncover complex neural mechanisms, bringing us closer to understanding how consciousness (the "software") works and how it influences the encoding of information in memory (the "hardware").

Above all, it was a great personal challenge to engage in the programming of an application without prior advanced programming skills. Moreover, I now recognize that the way I first approached this problem was not the right one. I relied too much

on the use of AI tools without understanding the conceptual depth underlying the code. I was distracted by the need to write a monotonous code and couldn't focus more on the theory of neuroscience. As the weeks passed, I realized that implementing the task wasn't as simple as expected. There were continuously new challenges, new requirements and new bugs to be solved. In parallel, I did not feel the same sense of accomplishment as I usually do when engaging in intellectual activities. As a result, my attention often drifted to other tasks. In a sense, I felt little agency over my work. Soon, I realized that I was wrong about this approach.

At that point, I decided gradually to retake control. With the help of one of my supervisors, undertaking a process of rewriting the code logic, arranging the snippets more clearly and creatively paved the way for improvement. It was during that period that my best reflections about the protocol emerged and I felt an increase in my overall mood, not only at the lab. I regained agency. That was the most enriching lesson of this summer. Engage in actions in a way that you control them, that you struggle and that you focus on the task without being distracted by posterior steps that seem more attractive. Even if the next steps may seem more appealing, failing to fully engage in the current one leads to passivity and low sense of accomplishment, which inevitably results in dissatisfaction. From now on "Take Control" will remain a motto that I follow. It isn't just a self-improvement exclamation but is a reminder to engage in actions in such a way that one feels more agency in accomplishing them. This is why one should aim to do things in their own way, which comes closer to their subjective self. Otherwise, one might never be satisfied, despite illusory success.

Appendix A

Moral and legal implications of sense of agency

A.1 Agency in Law

The sense of agency is fundamentally tied to one's identity and autonomy. It arises from the realization of free will and grounds the belief in a person's ability to control their own actions (Wen and Imamizu, 2022).

Legal systems are grounded in the principle of criminal responsibility, a concept that can already be traced back to Roman law. *Mens rea* reflected the intentional dimension of justice (Haggard, 2017). The underlying assumption is that healthy adults are aware of their intentions, actions, and outcomes. Accordingly, individuals who lack such awareness, which happens in low-agency situations, cannot, in principle, be held fully responsible for their behavior. Law therefore distinguishes between intended and unintended actions, with the attribution of intention depending largely on whether the individual experienced a sense of agency over the act. For this reason, factors such as age and emotional maturity are considered in homicide cases. Emotional intensity is another important factor. On the one hand, prolonged abuse can profoundly disrupt cognitive mechanisms, undermining self-control.

On the other hand, evidence from animal research demonstrates that rats with prior experience of control over a stressor demonstrate resilience when later exposed to uncontrollable stress. This indicates that a history of agency can act as a neuroprotective factor in high-stress contexts by fostering resilience and supporting adaptive behavior. Such experiences not only reduce behavioral responses to future stressors but also attenuate neurochemical reactions related to stress response (Maier and Watkins, 2010).

In practice, the legal application of these principles remains complex. Claims of diminished responsibility may bring secondary gains. Proving genuine innocence is challenging when judgments rely heavily on the measurement of subjective experiences.

Another important aspect is that individuals often engage in excessive behaviors when acting under orders, as the reduction in perceived responsibility diminishes their sense of agency. This phenomenon was illustrated in Milgram's obedience experiments.

A.2 The Milgram Experiment

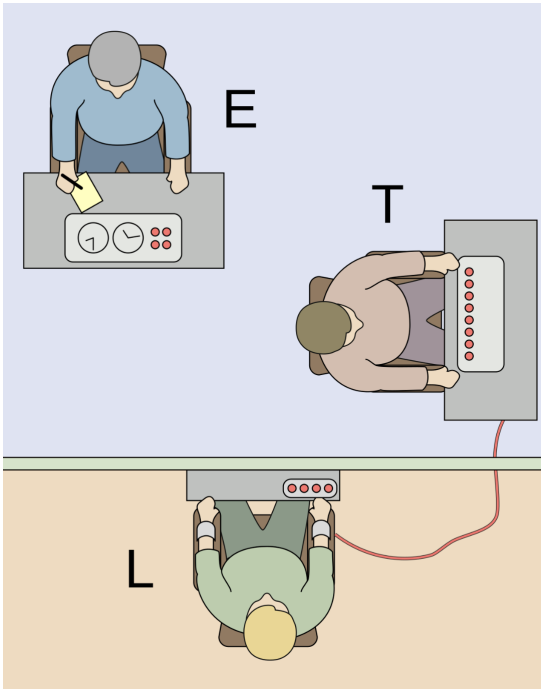

FIGURE A.1: Representation of the setup in Milgram's obedience experiment. The experimenter (E) instructs the teacher (T) to administer electric shocks to the learner (L). Source: Wikipedia.

After World War II and the Holocaust, several Nazi war criminals, including Adolf Eichmann, a key figure in the organization of deportations, defended their actions by claiming they were "just following orders." This line of defense deeply shocked and influenced Stanley Milgram, who set out to investigate whether obedience to authority could lead ordinary individuals to commit harmful or even criminal acts.

In Milgram's experiment, participants were instructed to administer what they believed were electric shocks to "learners," who were in fact actors. Although no real shocks were delivered, participants were led to believe that the shocks could escalate to dangerous levels. Strikingly, many participants continued administering them when instructed to do so, despite signs of distress. Individuals acting without authoritative pressure tended to stop much earlier.

These findings highlight the extent to which obedience can diminish the sense of agency (Haggard, 2017). Participants show reduced brain activity associated with action monitoring when they act under orders compared to when they act independently.

Milgram's experiment demonstrates that ordinary people may commit extreme or immoral actions when acting under coercion, as diminished agency creates psychological distance from the consequences of one's behavior. Nevertheless, obedience cannot excuse harmful actions: individuals remain morally responsible and must critically assess the ethical implications of their choices before acting.

Appendix B

Bias in the Perception of Agency

A well-documented bias in human cognition is the tendency to experience an exaggerated sense of agency when the outcome of an action is positive, even if the actual causal contribution of the individual is uncertain. For example, when a reflexive action or a behavior of questionable impact leads to a desirable result, people tend to feel disproportionately responsible for it and correspondingly more confident that they were the true agent of the outcome (Bandura, 1982). This bias illustrates how the sense of agency is not always a faithful reflection of causal reality but can be shaped by motivational factors.

An important question is whether such an exaggerated sense of agency extends to the domain of memory. When participants are asked to respond to recognition or recall questions, do they also inflate their confidence in situations where their actual influence is ambiguous or limited?

In this context, depression offers a particularly interesting contrast. Indeed, depressed individuals may adopt a more realistic view of their own agency and confidence (Haggard, 2017). This observation raises the possibility that while a heightened sense of agency can foster motivation (Ren et al., 2023), it may also distort accuracy in self-evaluation, whereas reduced agency might come with a closer alignment between subjective experience and objective reality.

This bias is also visible in modern human–machine interaction. A contemporary example can be found in the use of generative AI tools. When users receive positive feedback on AI-assisted outputs, they often convince themselves that they were the sole creators of the work, reinforcing an inflated sense of authorship and agency. Conversely, when feedback is negative, users tend to externalize responsibility, attributing errors to the AI system itself rather than acknowledging their own role.

Appendix C

Research Poster

Above is the research poster summarizing the work I presented at the Laidlaw Scholars Research Symposium.

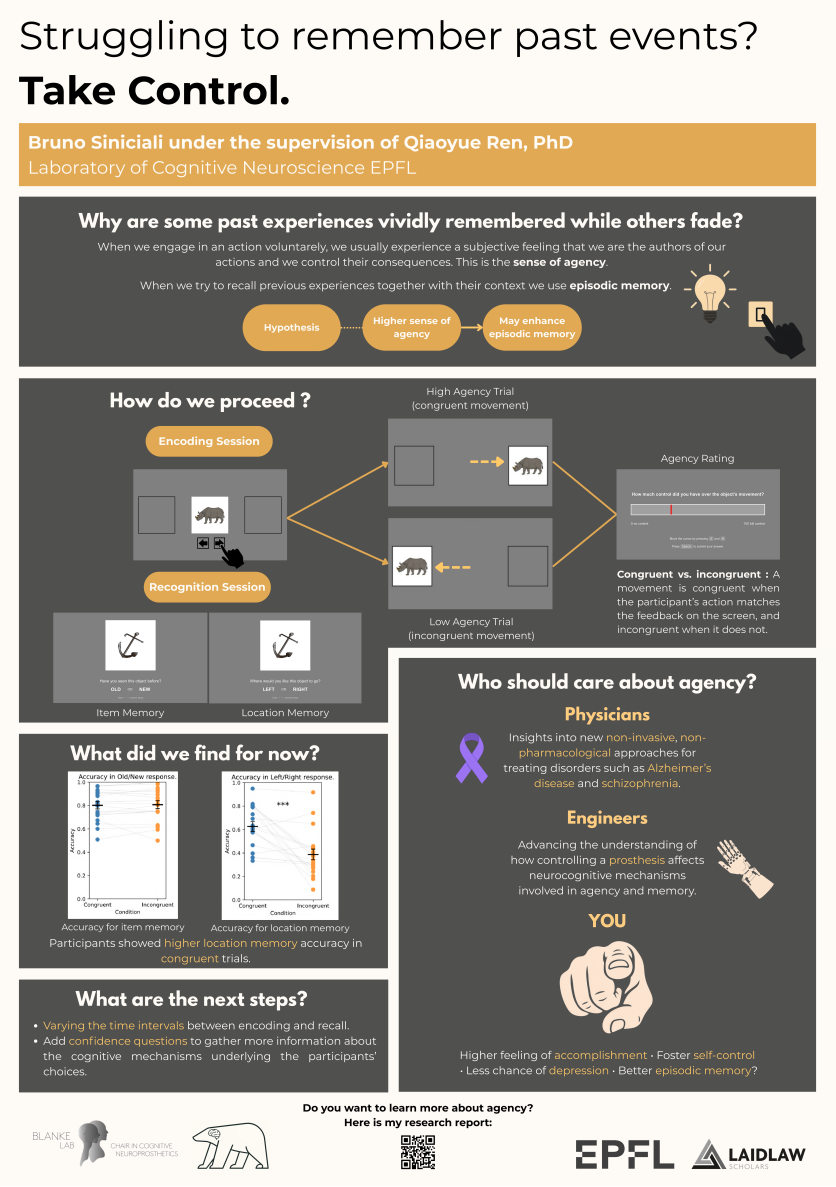

FIGURE C.1: The poster outlines the experimental design, presents preliminary findings showing and highlights implications for clinical practice, human–machine interaction, and everyday life.

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Glossary

Sense of Agency	The feeling of control over one's own actions and their effects in the environment.
Episodic Memory	The ability to recall specific events together with their context from one's personal past.
Congruent Trial	The event in which the outcome of an action matches the participant's intention or input.
Incongruent Trial	The event in which the outcome of an action does not match the participant's intention or input.
Volition	The cognitive process of making a conscious choice or decision to perform an action, often considered the mental initiation of voluntary behavior.
Forward Model	A computational mechanism of motor control in which the brain generates an internal prediction of the sensory consequences of an action before the action is executed.
Efference Copy	An internal copy of a motor command sent by the brain to predict the expected sensory consequences of an action, enabling comparison between intended and actual outcomes.
Pre-supplementary motor area	A region of the brain located in the medial frontal cortex, implicated in higher-order aspects of motor control, including action planning, and decision-making about voluntary movements.
Temporo-parietal junction	A cortical region situated at the boundary between the temporal and parietal lobes involved in integrating multisensory information and distinguishing self from others.
Angular gyrus	A region of the brain located in the parietal cortex, involved in spatial cognition, memory retrieval, and aspects of attention.
Insula	A region of the brain located in the cerebral cortex,involved in functions such as interoception (perception of internal bodily states), emotion, risk processing, and integration of sensory and affective information.

Precuneus	A region of the brain located in the medial parietal cortex, associated with visuospatial imagery, episodic memory retrieval, self-referential processing, and aspects of consciousness.
Striatum	A region of the brain located deep within the forebrain, forming the main input hub of the basal ganglia, involved in the regulation of voluntary movement, action selection, reward processing, and the integration of motivational information to guide behavior.
Medial temporal lobe	A region of the brain located on the inner surface of the temporal lobe that includes structures such as the hippocampus and the amygdala. It plays a critical role in memory, particularly in the encoding, consolidation, and retrieval of episodic and semantic memories.
Dorsal premotor cortex	A region of the brain located in the frontal lobe, more precisely the anterior to the primary motor cortex, involved in the planning and selection of voluntary movements, motor learning, and the integration of sensory information to guide action.
Occipital cortex	A region of brain, primarily responsible for visual processing.