Master Thesis on Cognitive Systems and Interactive Media

Universitat Pompeu Fabra

Hacking into the Memory Palace

A study on the effects of Spatial Clustering and Active Learning on Item Memorization.

Pau Benazet I Montobbio

Supervisors: Martí Sánchez Fibla & Daniel Pacheco Estefan

July 2023

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Dedication

To Laura, my pillar.

To Gunnar, my guardian angel. *Descansa en pau. T’estimo moltíssim.*

To my family, for their unconditional love and support.

Acknowledgments

Special thanks to Daniel Pacheco Estefan for aiding me in bypassing the roadblocks found during research of this project, his guidance was essential at many steps during this process and crucial to the quality of the project. Thanks to Martí Sánchez-Fibla, for his early guidance and supervision of the process. To the CSIM teachers in general, for awakening in me the passion for cognitive science and research. To APPIA for allowing me the flexibility to pull off this master thesis while being able to economically support myself. To Thalamus for all the empirical knowledge gathered in the field of VR and the use of their pre-existing templates and frameworks for development. To all the colleagues taking part of the CSIM master's program, providing me with valuable insights, council, and much needed relaxation.

Abstract

Plenty of research has been conducted on the role of space in organizing memories. Recent studies indicate a connection between spatial clustering and free-recall memory performance. However, the long-term stability of this effect remains poorly understood.

While voluntary learning is known to benefit memory, little research has explored whether actively creating spatial structure and information clusters offers additional advantages compared to passive scenarios of previous studies.

To address these questions, we created an original, fully immersive virtual reality setup. In the first experiment, we investigated the role of semantic organization in memory and its relationship with spatial clustering. Participants were presented with items categorized under clear semantic groups and were tasked to organize and memorize them spatially. The semantic organization of memory outperformed other methods (e.g., temporal or spatial organization) and remained evident even after two weeks.

In the second experiment, we eliminated semantic clustering to examine the effects of volition and active creation of spatial structure and its relation to spatial and temporal clustering. Actively creating and organizing spatial structure significantly reduced forgetting rates for the memorized items. While spatial and temporal clustering were observed immediately after the tests, they were not present after the two-week period.

These findings highlight the crucial role of volition in encoding and retaining information, suggesting that actively creating memory structure (spatial, semantic, or temporal) is fundamental for long-term declarative memory. Additionally, the study revealed the persistence of semantic organization over time, whereas temporal and spatial organization vanished after two weeks, indicating different roles in short-term and long-term memory organization.

This study offers valuable insights for the development of new learning techniques, memory-friendly environments, and spatial computing interfaces.

Keywords: Spatial Memory; Spatial Clustering; Semantic Clustering; Memory Palace; Active Learning; Long-term memory.

1. Introduction

Human memory and its mechanisms are widely researched topics. Nonetheless there are still plenty of gaps in knowledge on how we interpret our surroundings, encode them, and maintain the memories thereby formed.

1.1. Problem Statement

It has been shown that actively, i.e., volitionally, encoding information (learning) leads to improved memory performance as compared to passive exposure to information.[1–4]

Another of such mechanisms is the act of clustering information in chunks to increase encoding performance in the working memory.[5] This mechanism has been shown to work at different levels, one of which being spatially.[6] Recent studies have analyzed that items closely situated in space are clustered together and have a stronger recall performance.[7,8]

A recent study has found evidence for spatial clustering positively affecting recall performance in a 24-hour delayed test, suggesting that the mechanism of clustering spatial information may have a role to play in the consolidation of knowledge in long-term memory.[9]

Mnemonic techniques have been known to mankind for millennia.[10] Recent studies have shown the validity of such techniques and their contributions to learning. Mnemonic training has also been shown to improve overall memory performance and aid in rehabilitation of memory impairments. [11,12] With the advancements of Virtual Reality technology, it has become easier to place humans in an immersive, controlled and ecologically valid experimental setup.

The recent study conducted by Pacheco & Verschure (2018), found hints at the potential role of clustering in the consolidation of knowledge in a 24-hour delayed test.[9] The authors express the interest in testing for longer delays, to investigate the strength of such consolidation. Also, to our knowledge, no research has been conducted on the effect of actively creating clusters of information.

The goal of this study is to build upon theirs, recreating their experiment in a fully immersive VR setup, while introducing the act of actively creating the clusters of items to be remembered. Results for this study will provide further insight into different organizational mechanisms of human memory, and potentially provide research directions for creating new techniques for learning and treatments of memory impairments, new designs for spaces for learning environments or treatment centers, or insights into how to design novel user interfaces.

1.2. State of the Art

Taxonomy of Human Memory

Philosophers, Psychologists and Behavioral Scientists describe memory as containing different abilities: Working Memory, which allows us to hold information briefly while we work with it, Episodic Memory, which gives way to remembering episodes of one's life, and Semantic Memory which stores our knowledge on facts of the world around us, among other abilities.[13] The process of episodic memory is divided into three processes: first, encoding information by perception and relation to past knowledge, storing it and maintaining it over time and retrieving it by accessing such information when necessary.[14]

One part of working memory which still needs further investigation is the so-called *episodic buffer.* The episodic buffer is a limited capacity system that provides temporary storage of information.[15] Evidence suggests that the hippocampus' encoding abilities might be important for the episodic buffer to function.[16]

Recent taxonomies of human memory separate it at the highest level between short-term and long-term memory. Long-term memory is then further separated into declarative memory and non-declarative memory.[17,18] This study will focus deeper on long-term declarative memories, such as episodic memory and semantic memory.

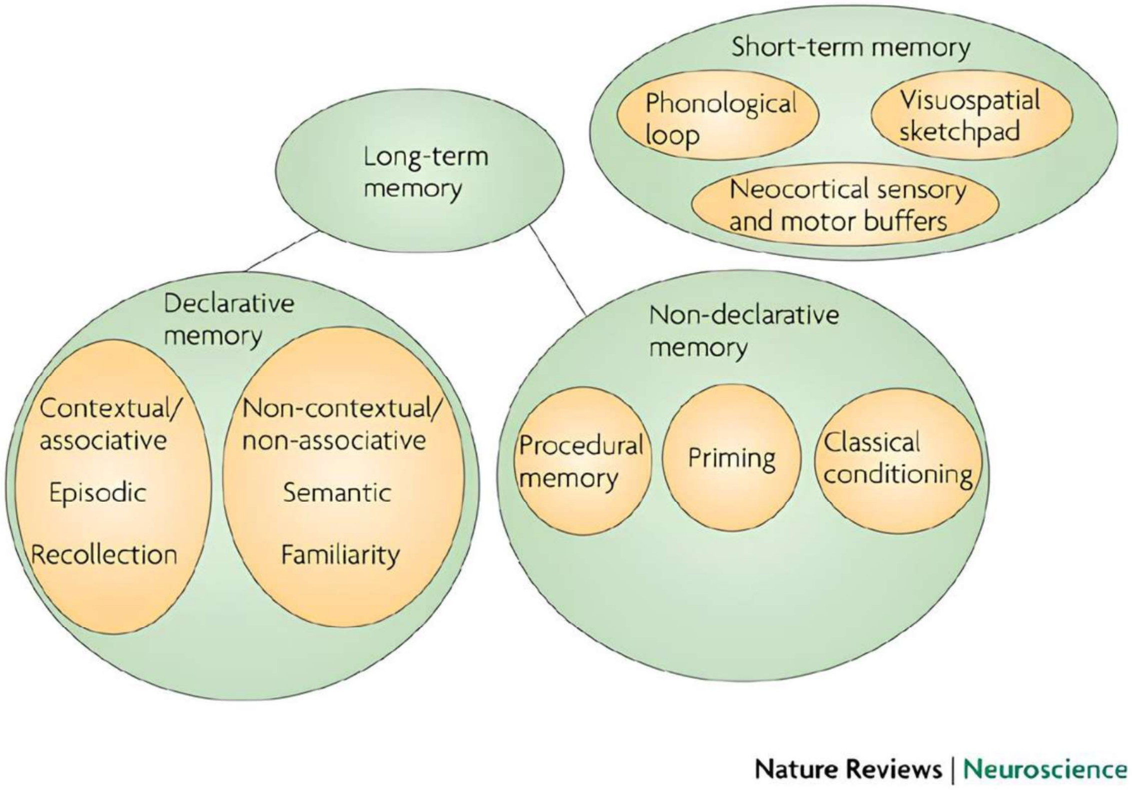


Figure 1: Traditional Taxonomy of Memory Systems. Taken from Bird & Burgess (2008)[17]

Mental Representation of Space (Cognitive Maps)

Consensus up to date suggests humans and other animals create a cognitive map of their surroundings. Cognitive maps can be understood as a three-dimensional representation of the space where the individual is situated, both locally and globally.[19,20] More concretely, some evidence points out that humans and other species that navigate three-dimensional environments, encode height separately from a two-dimensional plane, suggesting that three-dimensional spaces are represented in a quasi-planar manner, and not a fully volumetric map.[21]

Learning & Knowledge Retention

It is widely known that sleep and rest states consolidate memory and knowledge in humans, mammals, birds, and bees.[22–24]

Spatial knowledge retention performance has been seen to improve if the learning period is followed by a period of sleep. No further improvements were found after the following sleep periods. There is also a negative effect of sleep deprivation on knowledge retention, suggesting human spatial memory highly benefits if learning is hastily followed by a rest and sleep state. [25]

Recent models suggest that different types of memories have different forgetting rates, episodic memory being most affected by a sleep decay process.[26] Forgetting rates are calculated by simply counting what items which were previously recalled are no longer being recalled. To normalize forgetting rates, the number of forgotten items is divided by the total number of presented items at the encoding stage.[9]

Active Learning

Plenty of research has been conducted on the positive effects of active learning on knowledge retention and memory performance.[1,2,4,27] More concretely; recognition memory, declarative memory and long-term episodic memory have shown improved performance when volitional learning was performed by the subjects.[2,28,29]

Mnemonic Techniques

The key to increasing memory performance is both improving the encoding technique, creating associations with existing information, and improving retrieval by developing cues during encoding which will lead the person back through the information path.[13]

Mnemonic Techniques are different methodologies of learning new information and strengthening memory performance, some of them being used since ancient times.[30] They work by generating effective cues during the encoding process which can be easily recalled, thus facilitating the recollection of the acquired information associated with the cue. For cues to be effective, they must be related to the previous experience but not too similar as to not be confused.[31] It is important to state that mnemonic techniques are not comprehension tools, they are memorization techniques for information which requires recall.[32]

Studies have found significant evidence that mnemonic training boosts memory performance.[11,12] It has also been shown that mnemonic training aids in the rehabilitation treatments of memory impairments. [33–35]

One of the most well-known mnemonic techniques is that of the Method of Loci (MoL) or Memory Palace, which consists of creating connections between known locations (loci) and new information, then, to retrieve information one must simply walk through those locations mentally, and the cue should trigger the recall.[30,36] This technique takes full advantage of the Hippocampus and its observed role to handle encoding and retrieval of both spatial and episodic memory.[12,36–38] The Method of Loci has been proven to be an effective mnemonic technique to aid in recall of information in academic environments.[39]

Navigation

Consensus is that humans acquire spatial knowledge of their environment with three different methods.[40] One is Landmark Knowledge, by memorizing distinctive objects along our path. Another is Route Knowledge, by learning the sequence of directional choices at distinct intersections. This sequence of choices may be coded directly (e.g. left, right, left, left) or associating them with landmarks (e.g. left at the store, right at the church, straight until lake).[41,42] Lastly there is Survey Knowledge, where a cognitive map is formed from the navigated environment.[43] Survey knowledge appears to be position-independent and a major tool to enable shortcuts or bypasses in navigation of space.[19]

These studies suggest that during navigation, humans gather knowledge in a sequential manner: first gathering landmark knowledge, followed by route knowledge and finally completing it with survey knowledge.[40–42] This has also been found to be the order at which infants develop their navigational skills.[44–46] However, new studies propose that adults gather the three types of knowledge in parallel.[47]

Active vs Passive Navigation

Active learning has been shown to increase memory performance in visual recognition tasks, suggesting a connection between agency and the acquisition of knowledge.[48–50] In a similar line, active navigation has been proven to lead to greater spatial memory recall performance.[51]

Organizational Structures of Memory

Free Recall Tests

Free recall tests are a common task employed in the investigation of human memory. On free recall, participants must remember as many items as possible from a previously presented list, in any order in a given amount of time. Free recall tests usually present a serial position effect, i.e., items that were presented first and last are more likely to be remembered. This is due to the nature of free recall tests, in which subjects first initiate an associative short-term memory (last items presented) and a long-term, consolidated through rehearsal, associative memory (first items presented) stages, and, after an initial short burst of recalls, are observed to switch to a random memory search stage.[52,53]

It has also been observed that free recall enhances subsequent learning, due to the creation of mental schemas of retrieved knowledge. [54,55]

Memory Buffer and Clustering

It is suggested that humans have a cognitive ability to cluster information. Categorization processes are central to many human capabilities, and knowledge structures can be more general than objects and can possess more complex information than features.[56] Clustering allows for our memory to increase memory performance given our limited short-term memory buffer.[57] Current models of short-term memory and episodic memory include the assumption that people parse their continuous experience into episodic clusters.[58]

Temporal Clustering

Ample research has observed a temporal organization of episodic memory. Temporal context is predictive on the order at which recall occurs.[59–61] This means that items which are presented in proximal positions in time, have a higher tendency to be recalled together. As mentioned previously, there is a serial position effect for the first and last items presented, for they are, respectively, fresher in the working memory or more consolidated in long-term memory.[52,53]

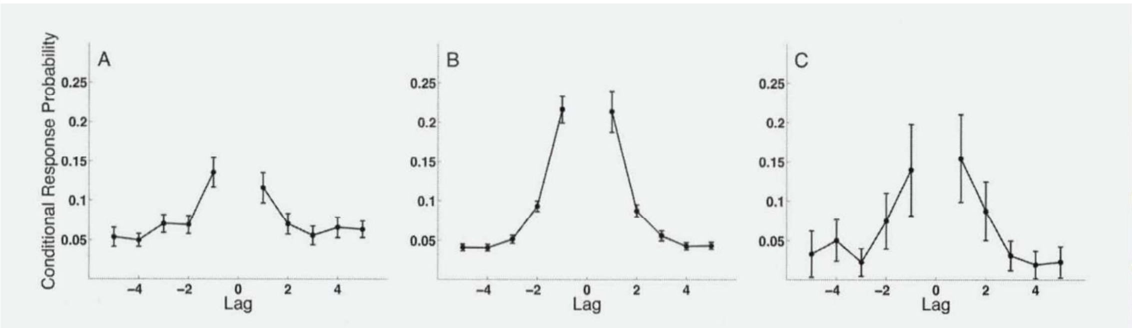


Figure 2: Conditional Response Probability as a function of temporal lag. In other words, for a recalled item in serial position i, probability of transitioning to proximal items (i + lag) in the presented list. Extracted from Miller et al., 2013.[7]

Semantic Clustering

An observed clustering of information, specially on free recall tests, is that of semantic clustering. Participants tend to organize their memories by making use of their pre-existing semantic associations among items.[62,63] This can be calculated by assigning a value to a transition based on the semantic distance between both recalled items and all other possible transitions from the presented list. To do so, we can make use of existing computational models of semantic spaces, such as word2vec.[64]

Spatial Clustering

Previous studies have shown that humans construct space in chunks of proximal objects.[6] This chunking, i.e., clustering, of visual information has been suggested to reduce cognitive load for subsequent memorization of items.[5] This points to an efficient mechanism of the human memory of packaging gathered visual and spatial information in the working memory.

A couple of studies found that the Euclidean proximity between objects is a strong predictor of the order in which they will be recalled, suggesting some sort of organizational system based on the spatial proximity of items. There was also a strong correlation between spatial clustering and recall performance found on these studies.[7,8]

Spatial Clustering can be quantified by calculating Spatial Clustering Scores (SCs). Similar to semantic clustering calculations, Spatial Clustering Scores are calculated by assigning a value to a recall transition based on the Euclidean proximity of the recalled item and the previous items, compared to all possible transitions. [7]

Spatial Clustering and Long-Term Memory

The mentioned studies conducted only immediate recall tests, providing insights into short-term memory, but a more recent study conducted by Pacheco & Verschure (2018) found that spatial clustering was also correlated for recall performance after a 24-hour period, pointing at the role of spatial clusters in increased memory consolidation.[9]

On their study, participants were tasked to navigate a virtual town and find certain items, on a randomized order for each subject. Once they reached said items, an image appeared for 2s, which they were asked to memorize. After conducting the trials, participants were subjected to a 90s free recall. After a period of 24 hours, participants received a surprise phone call and were subjected to another 90s free item recall. Pacheco and Verschure also tested for the effects of passive navigation, having a group of subjects only observe the movements of a previous participant. The experiments were conducted in a desktop VR setup.

The study found significant spatial clustering scores in both the immediate free recall test and the delayed recall test. The results also showed a correlation between SCs and recall performance, and a stabilization of SCs at T2 (24h later). Unexpectedly, they found no significant difference between the active and passive navigation of their virtual environment on SCs or recall performance.

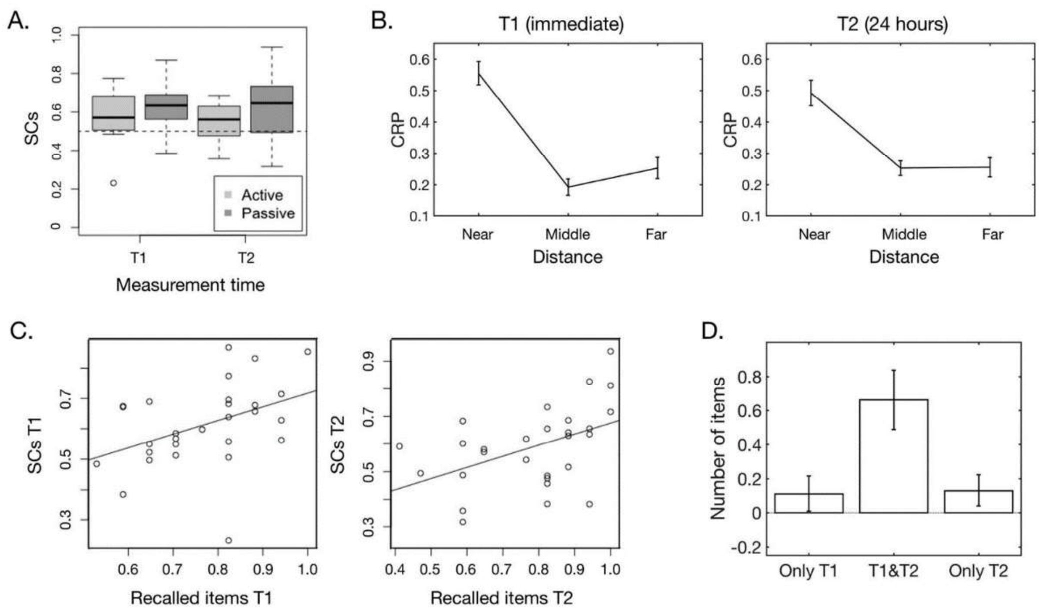


Figure 3: Results from Pacheco & Verschure's experiment 2. SCs for active and passive conditions, at T1 and T2. (A) RP as a function of distance at T1 (left) and T2 (right). (B) Correlation of SCs and recall performance in the immediate (left) and delayed (right) tests. Black line shows the least squares fit. (C) Number of items recalled only at T1, at T1 and T2, and only at T2. Error bars in panels B and D indicate ± standard error of the mean (SEM).

The study by Pacheco & Verschure also reported significant temporal clustering (TC) in their experiment 2, but no interaction between TC and SCs was found.

Virtual Reality as a Research Tool

Recent advances in Virtual Reality (VR) have ushered in a new wave of applications of the technology in the fields of education, training, healthcare and research.

Virtual Environments (VE) accessed through VR allow the researcher, educator, student or trainee to place themselves in contexts and situations that would otherwise be too costly, dangerous or outright impossible.[65] Novel VR tools, such as inside-out tracking Head Mounted Displays (HMD) like the Oculus Quest 2, allow for a wireless, near-seamless immersive experience with little to no hardware setup, and are proving to be even more reliable for tracking user data than previous HMDs.[66,67]

In the field of research, the effectiveness of VR tools compared to "real-life" equivalent scenarios and set-ups is currently disputed. There are some contradictory findings, especially on the performance of participants on given tasks.[68,69] Some criticism is also raised on the accessibility of such tools, which might have their performance limited by the skills of the research team.[70] On the other hand, other research advocates for VR experiences being an improvement on previous tools, providing greater control, ecological validity recollection of data and participant motivation.[71,72]

Literature review shows a necessity for conducted research to be accordingly updated, keeping it up to pace with technological improvements; the technological tools used, even on recent research, are not up-to-date and the hypothetical benefits of new advancements are not being explored to their full potential, if at all.

One field of research which has greatly explored the benefits of VR is that of Cognitive Science, given the ability to create controlled and repeatable, ecologically valid experimental scenarios.[73]

Virtual Reality in Memory Research

As previously mentioned, VR offers a great deal of advantages for certain research experiments; greater control, automated data gathering, participant motivation and increased ecological validity.[71–73] VR-based memory tests are observed to be well-accepted by most participants and replicable across laboratories and subject samples with little variation.[74]

Several studies on memory have been conducted benefiting from the use of Virtual Reality, mostly focused on spatial and navigational memory tasks.[73,75,76]

Virtual Reality and Immersion

Immersion, not to be confused with Presence[77], is a concept to describe the degree of involvement with a virtual experience or virtual environment. Originating from the gaming culture, research has tried to categorize and quantify the concept.[78] Three levels of immersion have been proposed: engagement, engrossment, and total immersion.[79] These three levels of immersion can be measured through both qualitative data (questionnaires) and quantitative (metrics gathered during the immersive experience).[79]

When experimenting of VR-based tasks, there is substantial evidence that more immersion is related to greater task performance. Specially on cognitive tasks, more immersion is linked to better recall and spatial recall performance.[80–82] Overall, HMD setups are preferred by participants and provide better results than traditional Desktop VR setups.[83,84]

Counterintuitively, hand tracking and realism of virtual hand models are not associated with a greater feeling of immersion, a hybrid approach of hand + controller being preferred by most participants.[85,86] Partially in contradiction, research suggests that the coherent tracking and movement of the digital self is more impactful on immersion than visual quality or auditorial features.[87]

Virtual Reality and Navigation

Virtual Reality has provided an exceptional set of tools to investigate human behaviors and navigation, and how they affect the formation of our cognitive maps and our memory. Similarly to Memory Tasks, those Navigational Tasks which can be performed in real-life perform better than those performed through Virtual Reality setups.[68,88] But virtual reality has allowed researchers to translate experiments which were only performed in animals, or in simulations, to the human condition and place participants in situations of sensory deprivation, confusion and extreme environments (to name a few) which would not be practical, ethical or even possible in real-life.[89]

A well-known limitation of immersive virtual reality experiences with HMDs is motion-sickness. It can manifest during a session due to different motives, but the most common one is during our navigation of the VE and due to a sensorial conflict between our visual input and our vestibular and proprioceptive perception.[90]

There are different ways to transverse an immersive virtual reality environment, but the most common are: joystick movement, teleporting, and walking.[91] Although teleporting provides an ingenuous, sickness-free solution for confined spaces, it may disorient users, thus making it not ideal for research scenarios, especially those concerning memory and spatial memory.[92]

Unsurprisingly, there is substantial literature pointing out that walking is the locomotive system which better performs on navigating virtual environments.[93] Research implies idiothetic information is crucial for a correct spatial learning in virtual environments.[94] Additionally, when vision and proprioception are sufficiently aligned, there is an improvement in one's self-location.[95] Participants who did VR-based tests using a walking locomotive method to navigate the VE showed improved accuracy in their environment cognitive maps as well as increased navigational performance and object retrieval.[96,97] Interestingly, participants who participated on a linear treadmill had statistically similar results than participants who participated in an omnidirectional treadmill, suggesting that rotational-body information has no substantial effect in spatial cognitive map building.[96]

As stated previously, active learning has been shown to increase the acquisition of knowledge.[48–50] There are also substantial differences between actively and passively navigating a virtual environment, with active participants having greater spatial memory recall performance than passive participants.[51] Surprisingly, a study on long-term spatial clustering in free recall found no significant difference on active versus passive navigation of the VE.[98]

Virtual Method of Loci

Instead of the traditional way (imagining a familiar place), researchers have investigated the impact of using a Virtual Environment during the mnemonic training.[80,99–105] Most studies observe that participants training using traditional Method of Loci (MoL) have an overall better or similar performance than those training using only the Virtual Reality powered Method of Loci (VMoL), although it is suggested that the use of VMoL may enhance the memory process nonetheless. Participants in such studies were also reported to have been more encouraged to use the MoL technique and with more confidence in the tool's effectiveness if they were presented with the virtual variant (VMoL) over the traditional one.[101,103,106] The cited studies have been conducted by using a variety of technological tools, from Desktop Virtual Reality, through 3DoF (only rotational tracking) HMDs to full inside-out tracking 6DoF HMDs. A higher performance was achieved with more immersive technologies. HMD beat traditional Desktop VR.[100,107] Most studies conclude that further research is needed to explore the full potential of Virtual Method of Loci training, including exploring the effects of increased immersion.[80,100,101,108]

A recent study done on the VMoL technique attempted to increase immersion by using the KAT-VR's Kat Loco sensors attached to the participants' feet. These sensors are a walk-in-place system which also transmits sensorial location of ankles to a virtual representation of the user's avatar in game, so it can see its own legs moving. Although the study found improvements with the increased immersive experience, it faced several limitations due to the COVID-19 pandemic, including a small sample size and limited training time for participants to get accustomed to the Virtual Environment.[109]

2. Methods

2.1. Research Questions

This study will build upon the findings of recent studies on the spatial proximity of items and the positive effect of such on memory performance.[7,8] Although plenty of research has been done on how spatial clustering improves short-term recall performance, little experimentation has been done on the effects on long-term memory, the study by Pacheco & Verschure (2018) finding a link between spatial clusters and recall performance in a delayed test.[9] Investigating this further may lead to a better understanding of the inner mechanisms of knowledge consolidation.

There is abundant research suggesting that an active role in learning greatly improves knowledge retention, but, to our knowledge, no research has been conducted in the active creation of spatial clusters of items, i.e., actively creating spatial structure, and its effects on short and long-term memory. Findings on this field may prove beneficial in creating stronger mnemonic techniques, learning techniques and memory improvement and rehabilitation treatments.[33–35]

The reviewed studies also shed light into how to properly conduct experimentation with Virtual Reality setups, as well as what aspects to control to ensure the best outcome. They provide insights on the strengths of Immersive Virtual Reality as a research tool which provides greater ecological validity and control.

We have also analyzed the different aspects of human navigation, human navigation in virtual environments, and how it plays a role in the construction of human memory.

From the state-of-the-art analysis, we pose the following research questions:

Q1: How does spatial clustering affect memory performance on long-term item recall?

Q2: How does active clustering of items, i.e., the active creation of spatial structure, affect memory performance?

Q3: How useful is fully immersive Virtual Reality for memory training? Will the observed effects from previous research be replicated or magnified?

2.2. Hypotheses

Given the abundant evidence for volitional learning improving memory and knowledge consolidation, and building in the previous studies on spatial clustering [7–9], we formulate the following hypotheses:

H1: Spatial Clustering Scores will be higher on the active clustering scenario.

H2: Actively creating the clusters of objects will have a positive effect on memory performance.

H3: Clustering and memory performance will be correlated in immediate and late tests.

H4.1: There will be a positive interaction between active clustering and long-term memory performance.

H4.2: There will be a negative interaction between active clustering and long-term forgetting rates.

2.3. Design & Development Criteria and Strategies

As previously stated, this study builds upon previous experimental setups, specifically the one conducted by Pacheco & Verschure (2018).

In their research, participants had to navigate a virtual environment of an old town through desktop virtual reality.[9] Since this study is planning to use a fully immersive VR setup, with tracked walking locomotion, the virtual environment must be reduced to accommodate the available space in the campus facilities, and hardware limitations of the selected HMD headset. (Meta Quest 2)

The introduction of two scenarios to test for active and passive clustering poses some challenges when designing the virtual environment and interactions. Mainly, the tasks, interactions and visuals must be near identical in both scenarios, isolating only the act of creating the clusters.

Extra caution must be taken when creating the list of items present in the experimental trials. Since the study aims to investigate spatial clustering, other dimensions of clustering must be avoided. For instance, semantic proximity must be minimal between all listed items.

Temporal clustering is expected to be observed in the results, but according to previous research, it will have no interaction with spatial clustering, given they modulate recall performance independently.[7,9] Either way, data must be properly collected to account for it and calculate possible interactions with other variables.

2.4. General Experimental Design and Set-up

The Loading Bay Task

The Loading Bay Task is an original experimental setup, adapted from previous spatial clustering studies, accounting for the hypothesized role of an active creation of such spatial clusters on memory performance.

Participants will be placed in the role of a worker in a loading bay, working for the fictional delivery company “Nozama”. Their task is to take boxes from the *delivery truck* and place them in the *sorting area*. Participants will be asked to memorize the items contained inside the boxes.

Experiment Loop

The main loop of the experiment is quite simple:

1. Every trial, the delivery truck will open its doors to reveal a box placed in one of three positions at random.
2. The participant will then approach said truck, grab the box and see the item inside. The item will be displayed for 3 seconds. This is an increase of 1 second, to account for possible immersive VR erratic motion, compared with previous research.[7–9]
3. The participant may then grab it and take it to the sorting area, where it can be placed. To account for different placement strategies (e.g., proximally sequentially, proximally semantically, by proximity to the participant due to laziness…), on each trial, 6 randomized available placement spots appear in the sorting area.
4. Once placed, another randomly placed box appears inside the delivery truck, and the cycle starts again.

Images of Items

Items were selected from a standardized pictorial dataset by Snodgrass & Vanderwart (1980), revised and coloured by Rossion and Pourtois (2004).[110,111] This is the same dataset used in previous studies.[1,9] The dataset also categorizes items by different categories, based on a large collection of subjective data, it also ranks items on their level of pertinence to any given category they are in as well as if they are repeated in more than one category.

Active versus Passive Clustering

Two sets of trials were conducted, to test for the difference of actively creating the spatial clusters of objects versus passively observing such clusters being created. To account for possible interference, the order in which the set of trials was conducted was alternated for each successive participant. E.g., Participant 1 will do the Active Set first (Fig. 1). Participant 2 did the Passive Set first, and so on (Fig. 2).

Active Set

The Active Set of trials involved the participant actively creating the clusters of boxes. (Fig. 4.B, 5.1 and 6.1)

Passive Set

The Passive set of trials introduced a virtual agent which sorted the boxes and created the spatial clusters. This agent was represented by a *sorting robot*, which took the boxes from the players and placed them on the sorting area according to data from the active set of trials from previous participants. (Fig. 4.C, 5.2 and 6.2)

Free Recall Test

After performing each set, the participants were asked to perform an item free recall test. Subjects had 90s to freely recall as many items as they could from the experiment in any order. After performing the experimental trials, participants were also asked if they followed any particular strategy when placing, memorizing and recalling the items, and if so, to briefly describe it.

To explore the effect of spatial clustering and the active creation of clusters on long-term memory, participants performed the free item recall tests at two different times:

T1: Immediately after each set of trials.

T2: Two weeks after experiment.

Free Item Recall tests at T2 were performed through a cold call. (Participants were asked to give their telephone number prior to the experiment but were not briefed as to why.)

All free item recall tests were audio recorded for later analysis.

Tutorial

Before partaking in the experimental sets of trials, the participants had to go through a tutorial scene, in which they learnt the main interactions of the experiment and familiarized themselves with the virtual environment. The tutorial scene ended when the participant correctly opened and placed 10 boxes.

Voice Over

At the start and end of every trial and recall scenes, there was a robotic voice over which gave clear instructions to the participants. Three different versions were created in the main spoken Languages in the Barcelona Area: Catalan, Spanish and English. During the tutorial scene, participants were encouraged to ask questions and solve any possible doubts they might have. A full script in English can be found in Appendix 1.

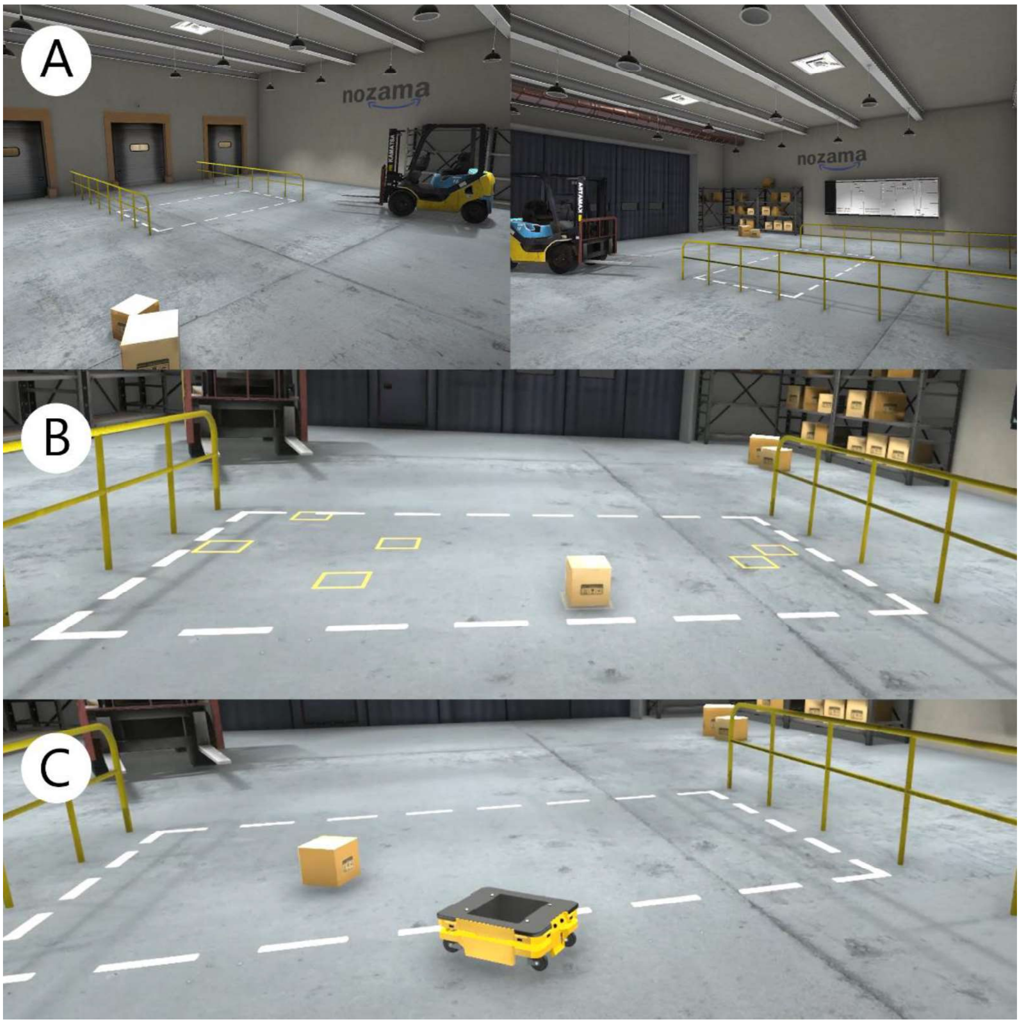


Figure 4: Different views from inside the software. General view of the "Nozama" warehouse (A). View of the Active Condition with the randomized placement zones inside the delivery area (B). View of the Passive Condition with the sorting robot waiting to be handed a new box to place (C).

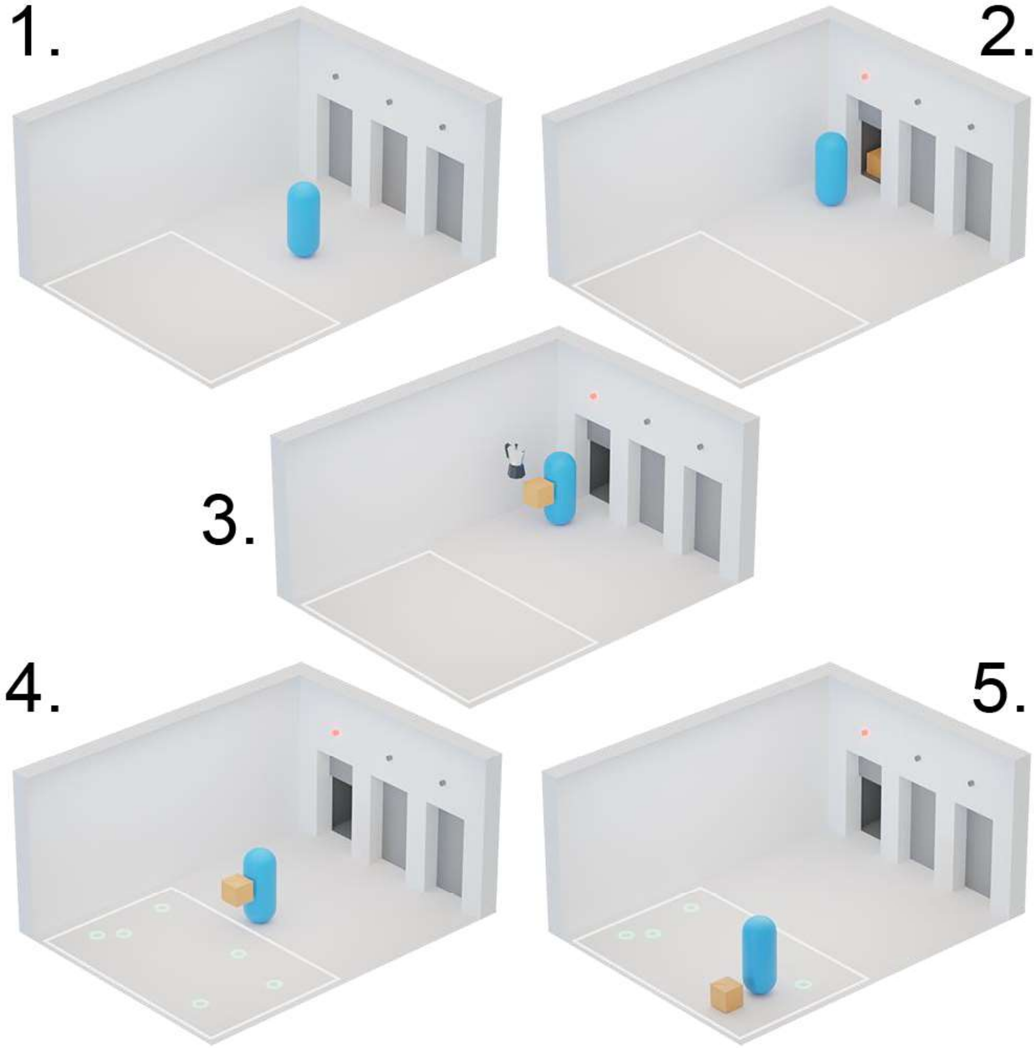


Figure 5.1: Simplified view of Active Set of Trials. 1. Participant starts in a 6x8m distribution center with 3 delivery doors and one sorting area. 2. A door opens revealing a box. 3. Participant grabs and opens the box. An item is displayed for 3s. 4-5. Participant brings the item to the sorting area and places it in one of the displayed randomized snapping positions.

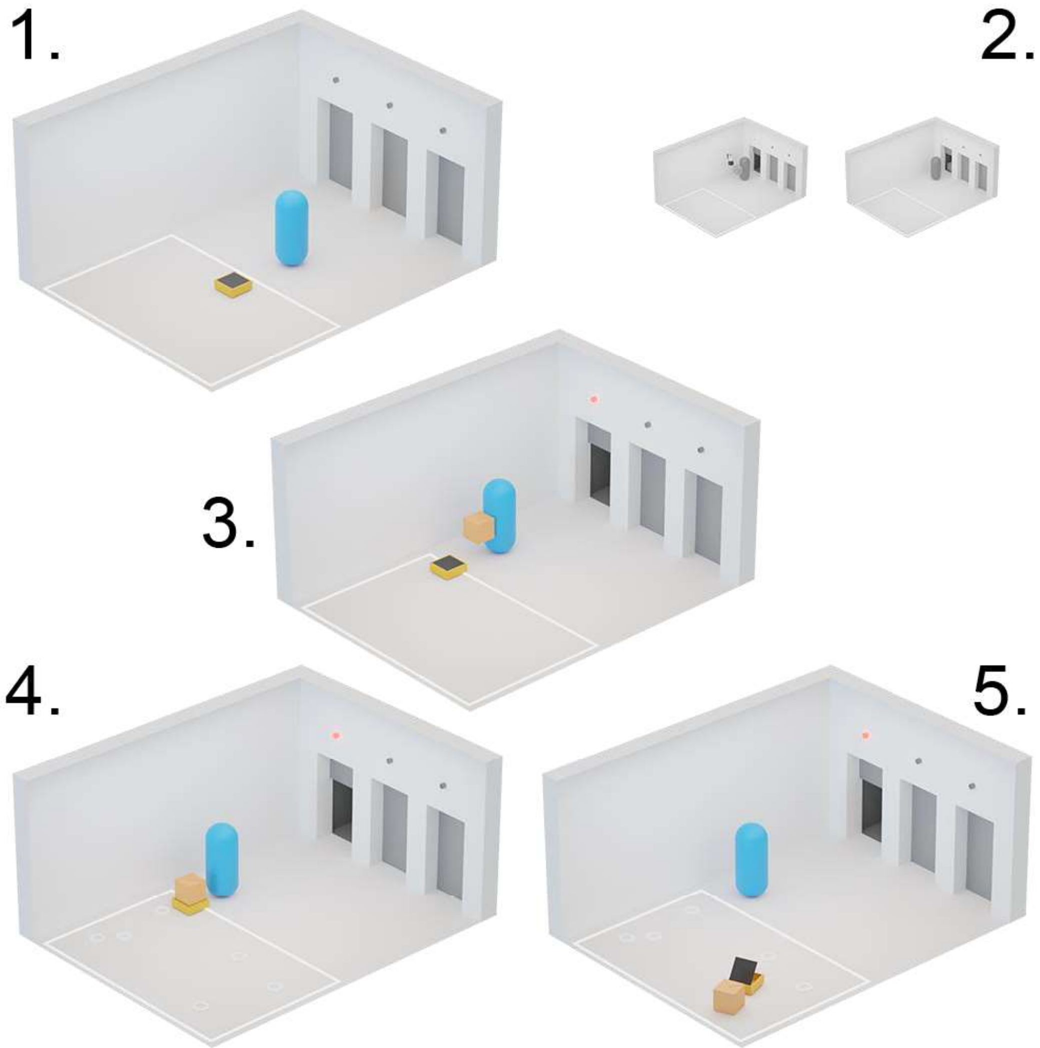


Figure 5.2: Simplified view of Passive Set of Trials. 1-2. The first steps are similar to the Active Set (Fig.1). 3-4. Participant brings the item to the sorting robot. 5. Robot places item following placement data from a previous participant's active set of trials.

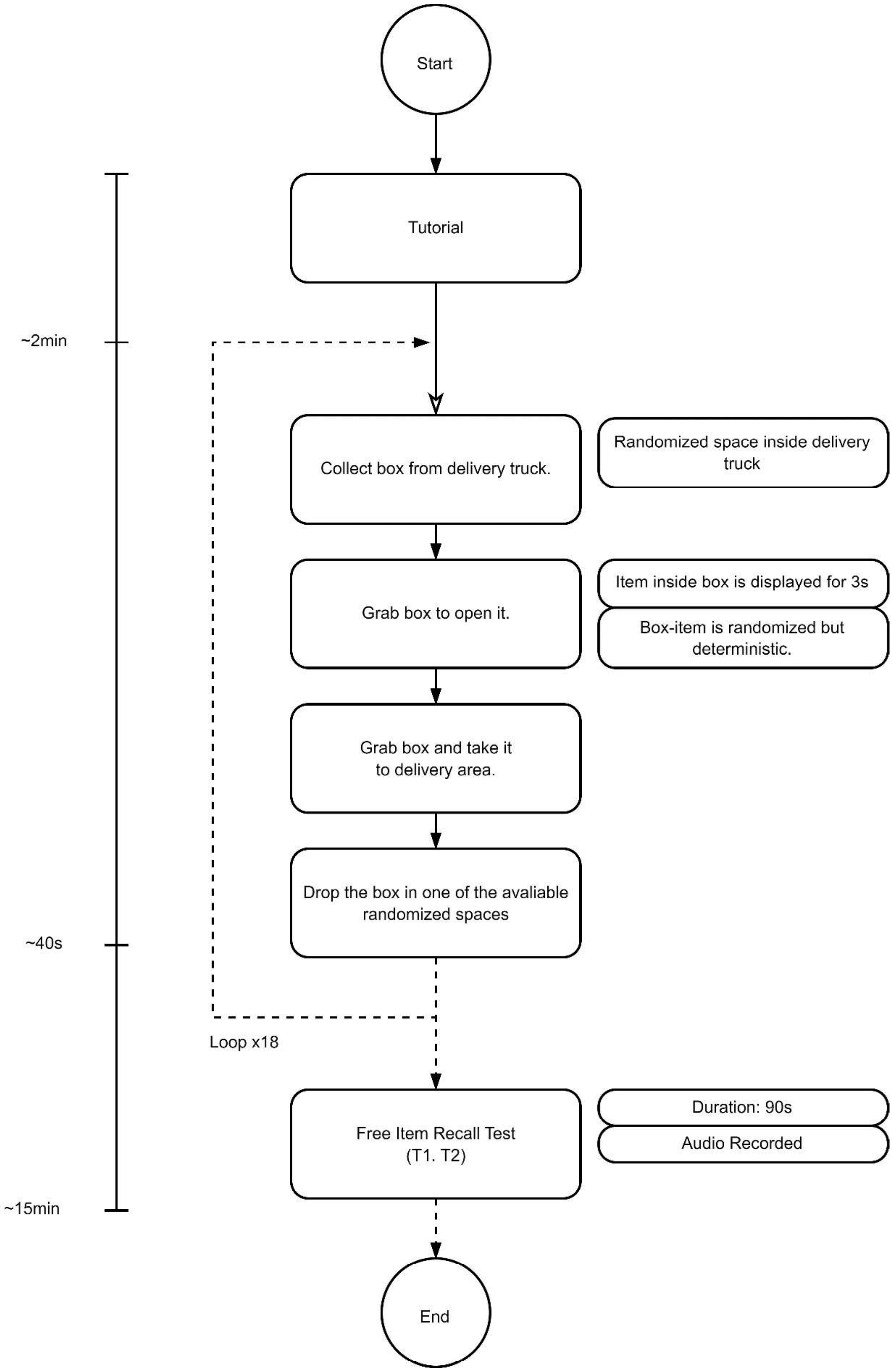


Figure 6.1: Experiment loops for the Active Condition.

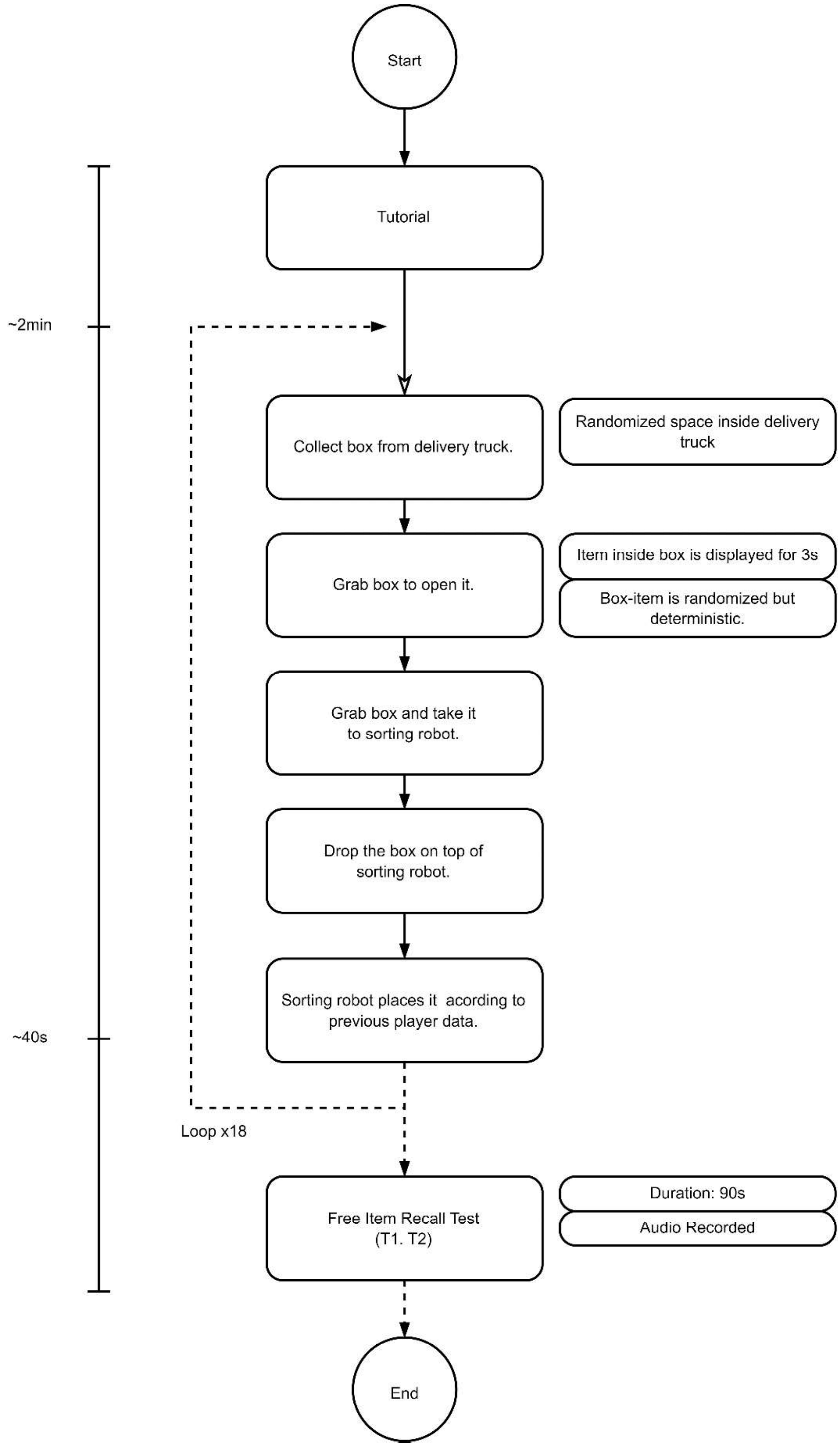


Figure 6.2: Experiment loops for the Passive Condition.

2.5. General Methodology

Participants

Participants were gathered through an online questionnaire in the general Barcelona Metropolitan Area. Selection criteria was as follows:

- Participants must be between 20 and 32 years old. (26 ±6)
- Participant must have no locomotive impairments.
- Participant must have no total or partial vision impairments.
- Participant must wear no glasses or wear thin-frame glasses.
- Participant must have no cognitive impairments.
- Participant must not have vertigo or other equilibrium impairments.

Extra steps were taken to ensure a balanced selection of biological sex male and female participants.

Ethics

Before starting the trials, participants were briefed on the experiment and the types of data which would be gathered. (Appendix 2) On the main menu of the experience, there was a menu with a button which participants had to press to start the experience, acknowledging they agreed to the collection and treatment of such data. After the experiment, on a voluntary manner, participants were asked for their biological sex given at birth as well as if they had any sort of learning impairment (e.g. Dyslexia) or had suffered from mental health related issues during the past year (e.g. Anxiety, Stress, Depression). They were also asked to confirm their cellphone number, previously collected on the sign-up form.

Only one type of identifiable personal data was gathered (cellphone number). Biological sex given at birth of the participant was also collected.

Materials

A custom software was developed for the experiment, using Unity Editor version 2021.3 LTS. 3D models were either downloaded from Sketchfab.com (CCA) or sculpted using the software: Blender version 3.5. (Fig. 4)

The VR App was capable of the following:

- Seamless movement inside the virtual environment through the inside-out SLAM (*Simultaneous Localization and Mapping*) tracking offered by the Meta Quest 2 Headset.
- The ability to grab and open virtual boxes. Boxes must display the item inside them for 3s, and only once.
- The ability to drop the grabbed box and drop it at a specified location.
- Randomizing order of item appearance as well as placement locations.
- Generating a file at the end of the experience with all needed data, including items final placement locations and distances to other items.
- Tracking the participant's movement, including head orientation.
- Tracking the time at which each action takes place.
- Recording the participant's voice during the free item recall session.

To conduct the experiment, a fully charged Meta Quest 2 VR Headset was needed. For redundancy, two headsets were prepared; one was charging while the other was being used. A dedicated room was needed which fit the fully immersive experience virtual environment size. This specific experimental setup needs a 8x6m room (48m2). (Fig. 7)

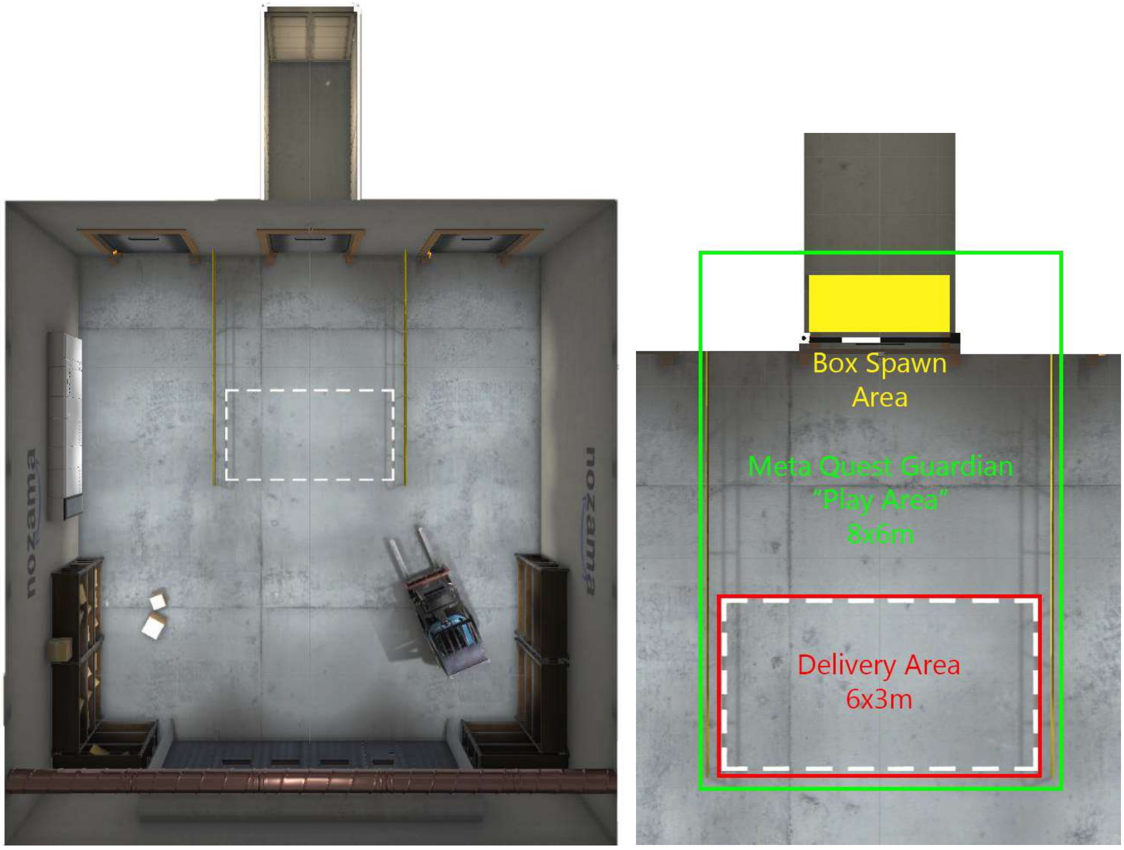


Figure 7: A top down view of the whole virtual environment (Left). A top down view of the actual "play area" and its dimensions in meters (Right).

The setup took advantage of the Meta Air Link system, which enables a fully untethered experience: all processing power is handled by a computer and sent to the headset via a high-speed wireless network. (Fig. 8)

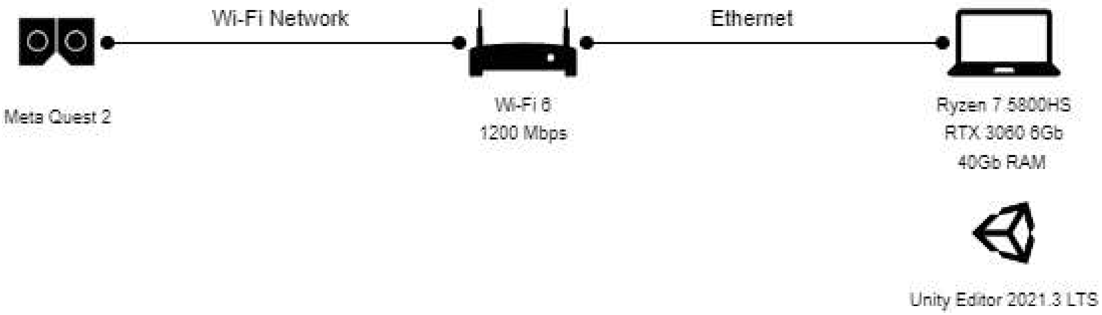


Figure 8: Schematic of the hardware used for the setup, including connections.

A Google Sheets document was created to gather the participants data and responses. This google sheets document is to keep track of participant information and to write down the participant's description of its sorting strategy (if applicable).

2.6. Procedures Used to Obtain Data and Results.

Data collection procedures were similar to those used in previous experiments on which this study is based, gathering data on recall performance, spatial clustering, and temporal clustering.

Virtual Environment Data

After a participant was finished with their trials, the software exported two CSV files; one containing the items presented and their location on the virtual environment (x,y,z), in order of appearance, and another containing the participants position and orientation for every 10ms, from which trajectories and head direction can be extracted. This data will be visualized to investigate possible future research paths. The time at which each participant action is performed was also be tracked.

Audio Data

A free item recall test was conducted after each set of experimental trials (active and passive). This recall test had a duration of 90 seconds, in accordance with previous research. The test was audio recorded, so the dynamics of recall could be analyzed. The free item recall test for both conditions (active and passive) will be performed at both recall times (T1, T2). From this test, recall performance was measured and given a score from 0 to 1, by dividing the number of recalled items to the total number of items during the trial. The recall order and time was also tracked, in order to assign the Spatial Clustering Scores.

Spatial Clustering Scores (SCs) are a measure of the tendency to consecutively recall items which were encoded at proximal locations. It is a value from 0 to 1 assigned to each recall transition according to the distance between the previous and current recalled item. In other words, when an item is recalled, if its location relative to the previous item is the smallest from all remaining non-recalled items, the transition will be given a score of 1, if it is the largest, it will be given a score of 0.

Time of recall of each item was also gathered since the start of the free item recall test. This will be needed to calculate both the recall time and the recall time between items.

Audio Data Analysis

Audio data was analyzed with the behavioral analysis software BORIS, an open-source video/audio coding software developed by the Department of Life Sciences and Systems Biology, University of Torino.[112]

A set of printed stickers with the images of the items was created to be stuck to the corresponding mapped keys in the keyboard, in order to speed up the analysis of the data.

Figure 9: Stickers placed on the keyboard for speeding-up the audio analysis and transcription with the BORIS software.

3. Experiment 1

The first experiment was conducted to analyze the influence of semantic organization of memory on performance and if it had any effects on the spatial organization of memory.

3.1. Setup

Selection of Items

The first experiment in the study conducted by Pacheco & Verschure found a ceiling effect in participants memorizing up to 13 items. They increased such number to 17 items in their second experiment, in which then found no ceiling effect.[9] On this first study, trials will each contain 20 items. Based on the categories created by Snodgrass and Vanderwart (1980), a list of 40 items was generated. (Appendix 3)

Items were selected following these criteria:

- Maximum 8 images per category.
- Images must have the highest scores of pertaining to such category, and appear in no other category.

For the tutorial, images not present in any related semantic category were selected from the standardized dataset.

Figure 10: Four example items - images of the same semantic category, as per Snodgrass & Vanderwart. [110]

Sample Size

The sample size for this pilot study was of N=18 (9 female) at T1, and also at T2, meaning all participants picked up the phone and agreed to the long-term recall test. Participants were 26±6 years old.

A power analysis conducted using G*Power (version 3.1) gave a result of Power = 0.99. The selected test was an ANOVA within items, post hoc, for 20 measurements, small effect size (η = 0.2), α = 0.05, assuming a correlation of r = 0.5 between repeated measures.

Ethics

Only one type of identifiable personal data was gathered (cellphone number). Biological sex of the participant was also collected. To ensure complete anonymity, participants were assigned an ID string consisting of: Day (*MMDD*) and Time of Experiment (*HHMM*) + Condition (A/P) (Active or Passive first) + Participant number on that condition, starting at 01. (e.g., participant performing the trials at the 25th of March at 18:15, doing the Active Set of trials first → 04251815_a01). See figure 5 for a graphic representation.

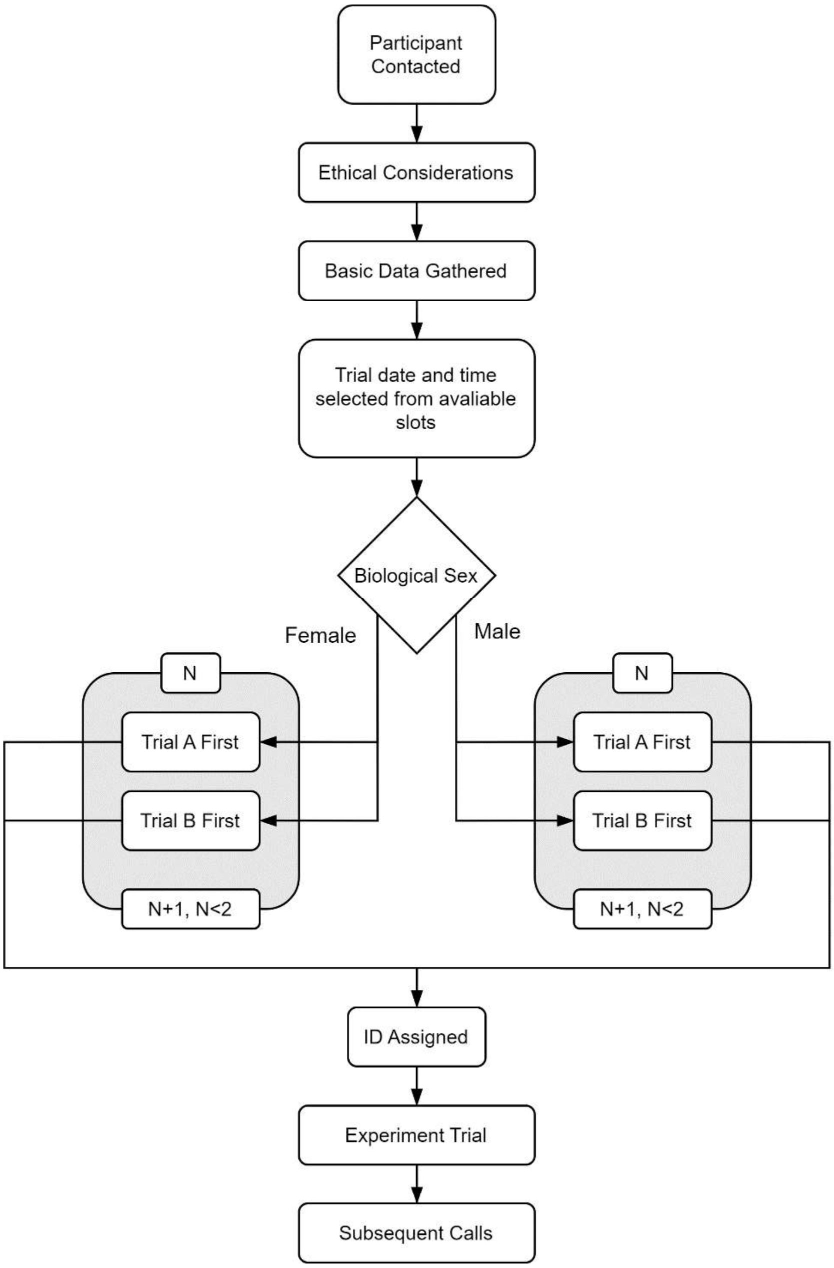


Figure 11: Overall flow of each participant. Participants are first asked for necessary data, prompted to select a date and time to perform the experiment, and then split by biological sex, to ensure equal representation in both conditions. They are then assigned one condition or the other in an alternating manner.

3.2. Experiment 1 Results

Spatial Clustering Scores

Significant SCs were only found in the Active Clustering condition at T1 (immediate) ($p < 0.001$).

P-values were calculated following a bootstrap method of 1000 randomizations based on each participant's recalled items, following a similar procedure to previous research on the topic. [7,9]

Performance

There is a significant difference in performance between Active – T1 and Passive – T1 ($p = 0.047$). On T2 performance is significantly low for both scenarios.

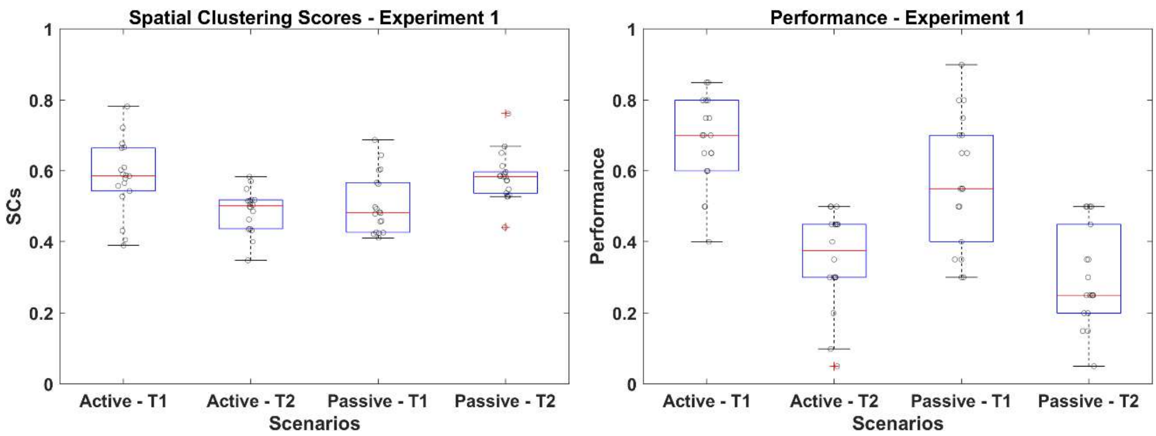


Figure 12: Left: Spatial Clustering Scores for each condition and recall time. Right: Performance at each condition and time.

Semantic Clustering

After witnessing these results and observing during the recall tests what seemed to be a strong semantic clustering by the participants, an analysis of semantic clustering was conducted.

A semantic distance matrix was calculated using the Word2Vec model applied to the items presented to the participants.[64]

Semantic Clustering scores were calculated similarly to Spatial Clustering scores, inputting the semantic distance matrix instead of the Euclidean positions of items.

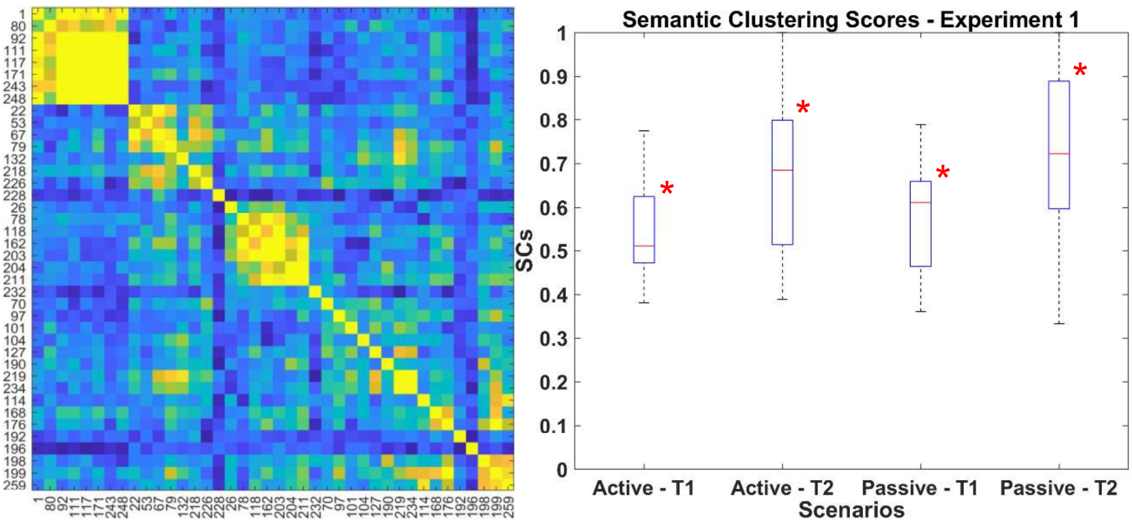


Figure 13: Left: Word2Vec semantic proximity matrix. There appears to be a clear categorization of presented items, corresponding to the categories of the Snodgrass & Vanderwart pictorial set. Right: Semantic Clustering Scores with p-values.

There is a clear semantic clustering mechanic being used by the participants, significantly in all scenarios and recall times. Respectively $p = 0.009$, $p = 0.003$, $p = 0.008$ and $p < 0.001$.

No significant interaction was found between semantic clustering and spatial clustering scores (SCs).

4. Experiment 2

4.1. Differences from Experiment 1

Two effects were detected in the first study:

1- There was a clear presence of semantic clustering amongst the participants. It was so strong; it might have overpowered other types of clustering (i.e.: spatial clustering) as an organizational mechanism.

2- When conducting the recall tests at T2, i.e., the phone calls 2 weeks after the experiment, there was a noticeable intrusion of items shown in the passive condition into the active condition, and vice versa. There was also intrusion of the images shown during the tutorial. This made recall data from T2 difficult to analyze and interpret, given the transitions between items were not clean.

To counter these effects, the following changes were made in the setup:

Passive versus Active Groups

To avoid intrusion of items from different conditions on the long-term recall test (T2), the experiment was changed from a within subjects to a within-between setup. Participants would now be split into two groups; group A only performed the active scenario and group B only participated in the passive scenario.

Selection of Items

To avoid a clear semantical clustering, a new list of items was created, following these criteria:

- Maximum 1 image per category.
- Images must have the highest scores of pertaining to such category and appear in no other category.

This led to a list of 18 items, which all participants in both conditions would share. (Appendix 4)

For the tutorial, no images were shown. Instead a logo for the fictional company “Nozama” was displayed where the images would be.

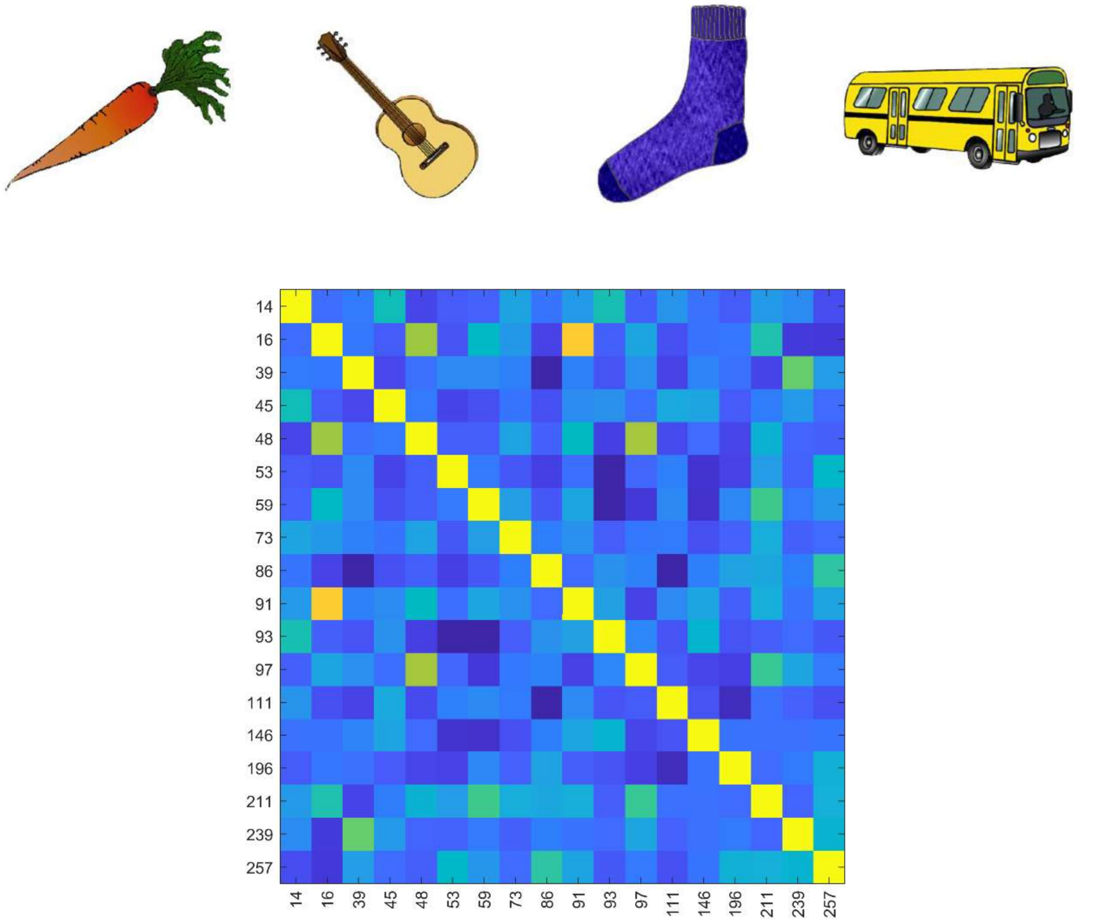


Figure 14: Examples of items – images selected of experiment 2, all from different semantic categories (top). Word2Vec semantic proximity matrix for the new 18 item list. No apparent semantic categorization found (bottom).

Sample Size

The sample size for the definitive study was N=36. For Group A (Active), N = 18 (10 female) for T1 and T2. For Group B (Passive), N = 18 (9 female) for T1, but for T2, N = 16 (8 female), due to two participants not answering the phone after repeated attempts to contact them. Participants were 26±6 years old.

A power analysis conducted using G*Power (version 3.1) gave a result of Power = 0.86. The selected test was an ANOVA within-between interaction, post hoc, for 10 measurements (average recalled transitions), small effect size (η = 0.2), α = 0.05, N.Groups = 4, assuming a correlation of r = 0.5 between repeated measures.

4.2. Experiment 2 Results

Trajectories

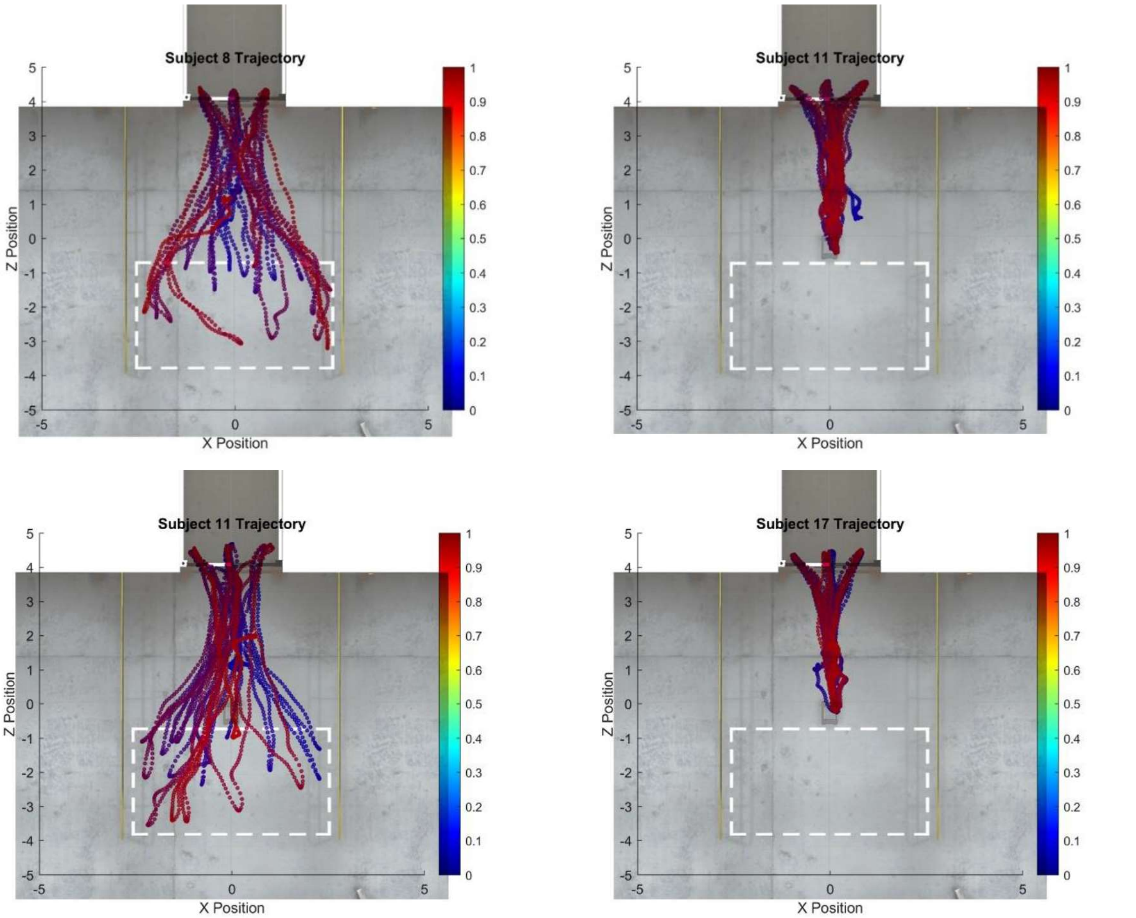


Figure 15: Left: Trajectories of subjects in the active condition. Right: trajectories of subjects in the passive condition.

Semantic Clustering Scores

No significant semantic clustering was found with the new 18 item list.

Spatial Clustering Scores

Significant SCs were only found in the Active Clustering condition at T1 (immediate) ($p < 0.001$).

P-values were calculated following the same bootstrap method of 1000 randomizations based on each participant's recalled items, as in experiment 1 and previous research.[7,9]

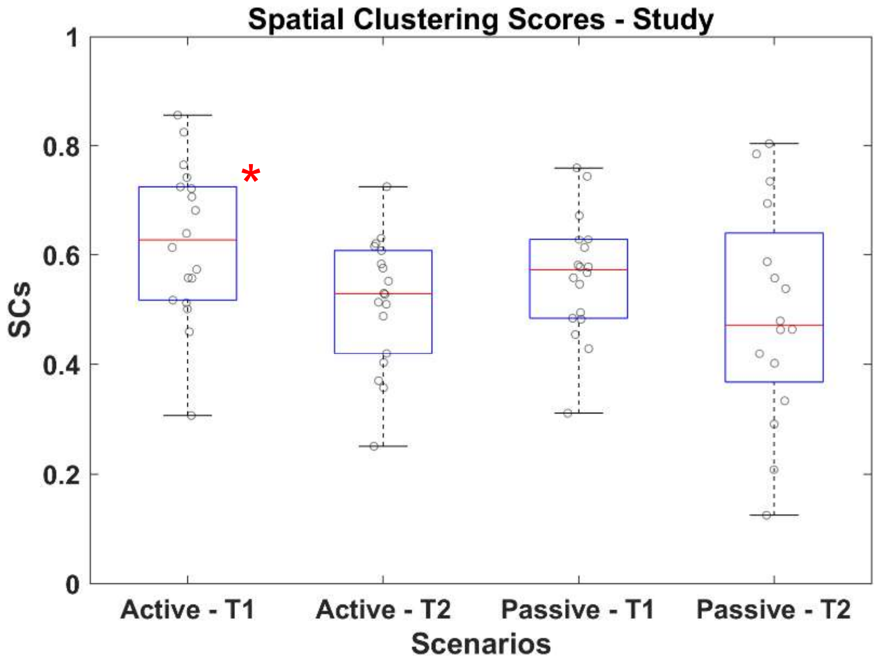


Figure 16: Spatial Clustering Scores for Experiment 2 in all conditions and recall times.

Performance

A Kruskal-Wallis test for non-normally distributed data was conducted after observing non-normality for the samples of performance in all scenarios. Performance was significantly higher at T1 for both active ($p = 0.0029$) and passive ($p < 0.001$) conditions, but no significant difference was found between Active T1 and Passive T1 scenarios, nor between Active T2 and Passive T2 scenarios.

No significant correlation was found between SCs and performance, in any of the scenarios.

Forgetting Rates

Since the data for forgetting rates was not normally distributed at the passive condition, a Wilcoxon rank-sum test was conducted. Forgetting rates were significantly lower in the active condition than the passive condition. ($p < 0.0001$)

Again, no significant correlation was found between SCs and forgetting rates.

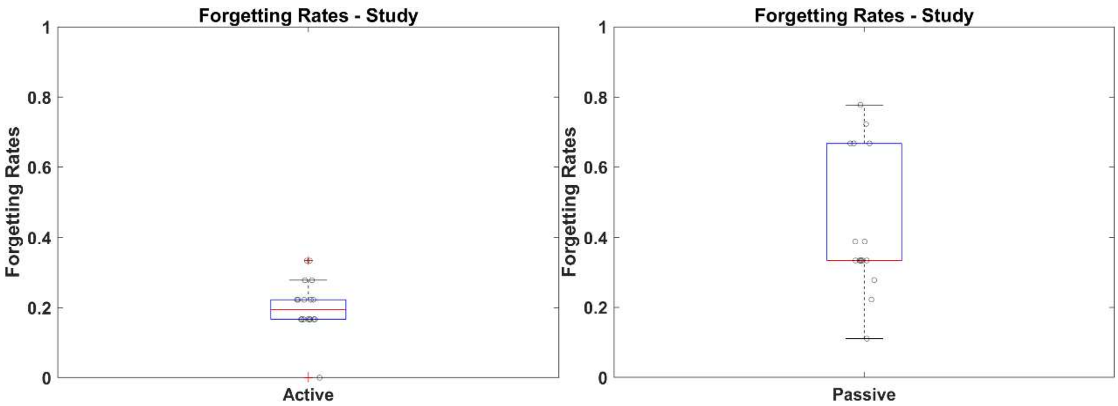


Figure 16: Forgetting rates were significantly lower and more consistent on the active clustering scenario.

Temporal Clustering

Temporal clustering was also observed at T1 for both active ($p < 0.001$) and passive ($p=0.012$) conditions. At T2 it is no longer present, for both conditions.

No significant interaction was found between temporal clustering and spatial clustering, performance nor forgetting rates.

No effect of mental health or learning impairments

Participants voluntarily reported if they had any learning difficulties (e.g. Dyslexia, ADHD…) or have been suffering from a mental health disorder during the past year. An analysis of the results was conducted first removing only participants with dyslexia, then only participants with ADHD and then only participants with mental health issues. No significant difference was found in the results from these analyses.

5. Discussion

This research project was created to analyze and understand the different organizational mechanisms of the mind, focusing on the spatial clustering effect found by previous researchers. [7,9]

On top of intending to reproduce previous findings, an original, fully immersive VR experimental setup was created to test for the effects that volition and the active creation of spatial structure might have on memory performance and the organizational mechanisms of the mind.

Although indeed finding the presence of a spatial organization of memory, as well as temporal and semantical, some of our results contradict previous findings, suggesting that the addition of volition and active creation of spatial structure plays a role in the organization and retention of memory.

From the results, four main findings can be structured:

Active Creation of Spatial Structure

On this research's experimental setup, a main difference on the encoding of memory was introduced; participants were actively creating the spatial structure to which the items memorized would be linked.

In this experimental setup, spatial clustering scores were observed, significantly so at T1 on the active scenarios in both experiment 1 and experiment 2, reproducing previous findings on the spatial organization of memory. The passive condition, in which the spatial structure was being built in real-time but by a passive agent, seemed to have a negative effect on the spatial organization of memory, SCs not being found in any of the experimental setups.

As for performance on short and long-term recall, active and passive scenarios did not differ significantly on the number of items remembered (performance), but conversely, forgetting rates were significantly much lower in the active condition, suggesting that actively creating spatial structure for memorization has a positive effect on the retention of information on long-term memory.

Contrary to previous studies, no correlation was found between spatial clustering scores and performance in any of the scenarios, indicating that the real-time and active creation of spatial structure affects how memory is structured and encoded.

This is a novel approach, which differs from previous studies and the usual memory palace techniques, in which the spatial structure comes already created, and the subject actively links items to it. In other words, in previous setups, the subject has a passive role in the organization of space and the items linked to it, in this study's setup, the participant was actively constructing said space, in real-time, by placing the boxes which contained the items they had to memorize. Even in the passive condition, spatial structure was not presented from the start, but was also created in real-time, although by a passive agent.

The observed results suggest that the real-time creation of spatial structure plays a role in how the human mind structures and organizes memory, counteracting to some extent the role of spatial clustering and temporal clustering. Actively creating such spatial structure is observed to aid in the consolidation of memory.

Another explanation as to why the results differ from previous studies might be the distances between presented items.

Long-term Organization of Memory

The main study this thesis is based on, conducted by Pacheco and Verschure (2018) found a permanency of spatial clustering as an organizational mechanism of memory 24 hours after the trials. Their study also detected that SCs became a better predictor for performance after the same 24-hour period, suggesting a stabilization of SCs, most likely due to sleep consolidation.

In contrast, our experiments set to explore if that effect could still be found 2 weeks (14 days) after the experiment. No spatial clustering was found after a two-week period. In fact, there was a complete disappearance of temporal clustering as well, which was observed in T1 but not in T2. The only type of clustering which was still observed at T2 was semantical clustering, but only in experiment 1, where semantic categories were explicit and detected by participants in T1.

These findings suggest that after a period of two weeks, spatial clustering and temporal clustering lose their organizational role of memory, giving way to some other kind of mechanism. The observation of sustained, and slightly increased semantical clustering at T2 in Experiment 1 points to a bigger role of semantic clustering as an organizational mechanism of long-term memory. In the case of Experiment 2, where no clear semantic categories were presented, an alternative, subjective semantic organizational mechanism could have been used by the subjects, as suggested by Tulving (1966) and further researched by Aurélien Frick et al., (2023).[113,114] Semantic memory structure may also vary from each individual and through time.[63]

Possible role of Scale in Spatial Clustering

The human brain's representations of space have been observed to be separated into different scales. Humans code information from smaller scale environments in different cortical regions than larger-scale ones.[115,116] A recent study suggests a new organizational model of spatial memory, going from more concrete processing in smaller-scale environments to more abstract in larger-scale ones.[116]

Previous experiments on spatial clustering presented a more spaced-out spatial structure, consisting of streets and alleyways, in which the participant had to navigate great distances to reach some locations where the items would appear.[7,9] Given this thesis intention was to test a fully immersive VR setup to increase proprioceptive information, distances were limited by the available physical space in which the experiments were conducted (6x8m). Items were all spatially distributed in an area of only 6x3m. (Fig. 7) The contradicting results found in our study of SCs and its non-correlation with performance could suggest that spatial clustering and its organizational and retention role in memory could be dependent on the distance between stimuli, pointing to a limited resolution on the lower scales boundary of the spatial clustering mechanism.

Further Research

By changing the setup in just a couple of parameters, this study found different results to previous spatial clustering research. This suggests that there are more elements and variables at play in the spatial and temporal organization of memory in short and long-term memory.

Our setup presented the user with a real-time, simultaneously to encoding, creation of spatial structure, and, in the active conditions, the subject actively participated in said creation. This provided a great increase in the retention of items but changed the expected behavior of spatial clustering and temporal clustering. Further research on both how an active creation of spatial structure and how the construction of spatial structure simultaneous to encoding affects memory organizational mechanisms and consolidation is needed.

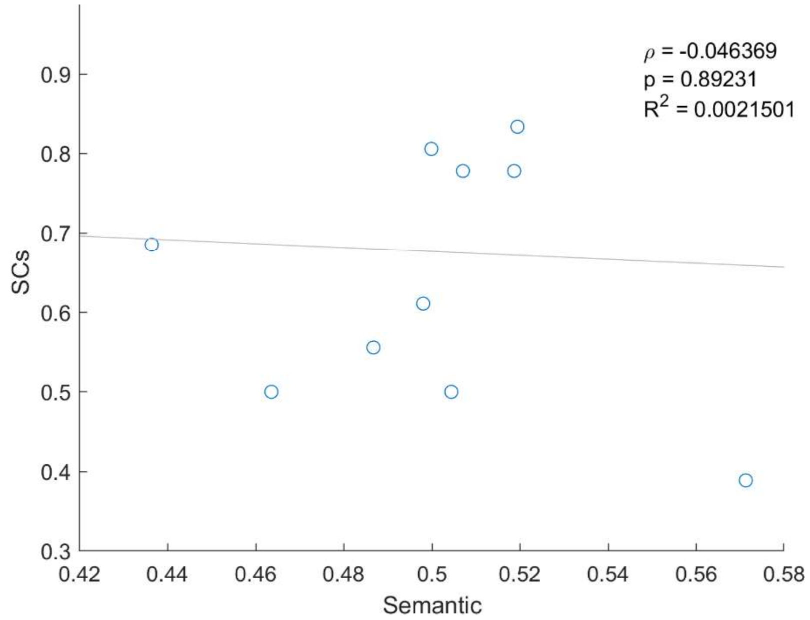
Our setup also tested for the appearance of clustering in a much greater time-delay compared to previous studies; we jumped from 24 hours to 14 days. We observed a complete dissolution of both spatial clustering scores and temporal clustering scores after a two-week period, but a permanence of semantical clustering in experiment 1, where semantic categories were explicitly chosen. This points at a shift of importance and roles of organizational mechanisms at different times of long-term memory. Further research at different time intervals (48 hours, 72 hours, and so on) would provide greater insight into how this shift might happen and what other mechanisms come into play.

This experiment proposed a proximity spatial clustering setup. The difference in results suggests that scale of spatial structure might play a role in the spatial organization of memory and its relation to performance and consolidation. Some further investigation on different scales of spatial structure could provide further evidence on the scales at which the human mind organizes spatial memory and how it may modulate the role of spatial clustering.

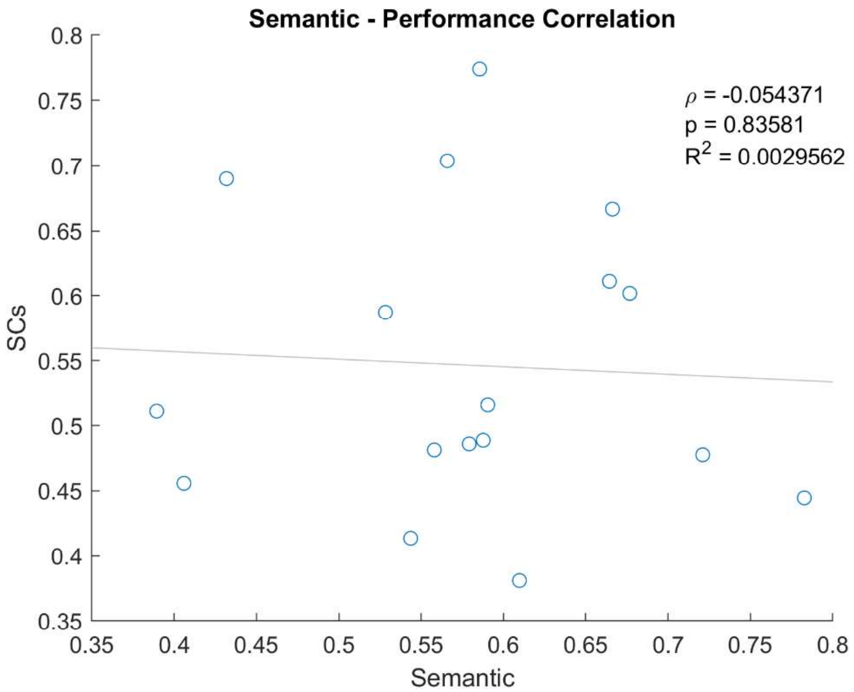
Finally, our setup continued the tendency of previous research of analyzing spatial organization of memory in a two-dimensional plane. No research has been conducted analyzing if the spatial organization of memory is also observed at a three-dimensional level, and if so, how a 3D structure influences performance and consolidation.

6. List of Figures

6.1. Experiment 1

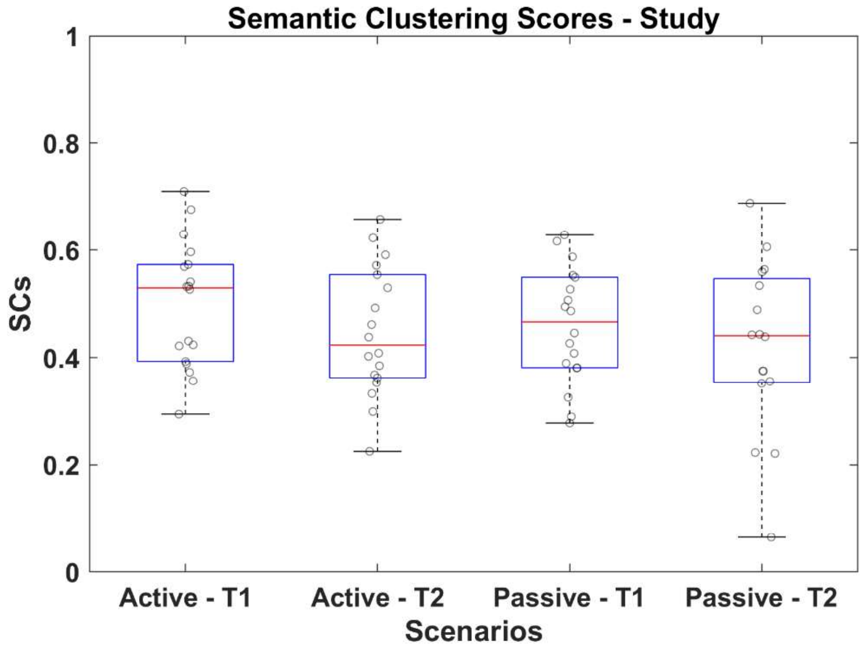


Correlation between Semantic and SCs in the active condition at T1 – Experiment 1

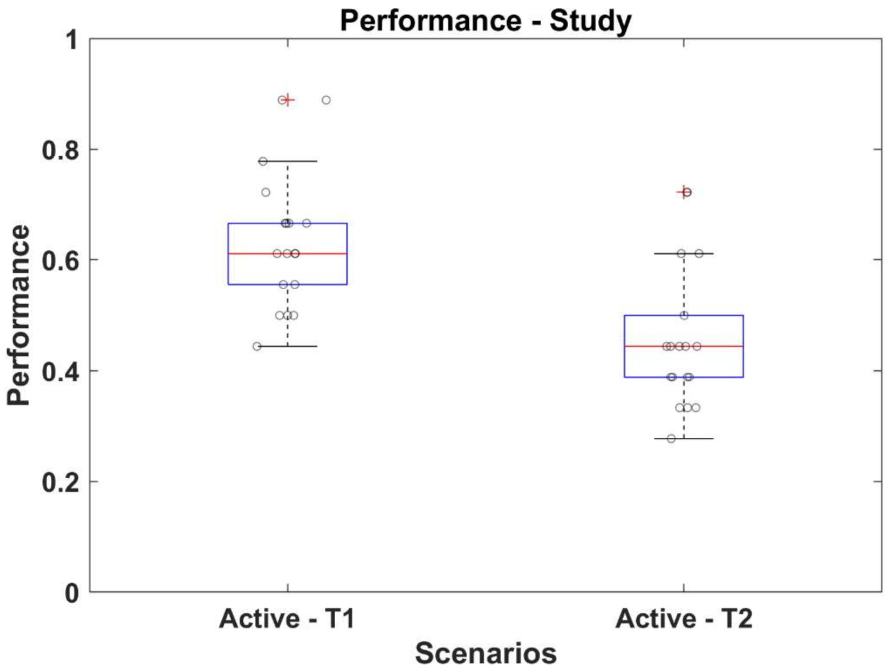


Correlation between Semantic and SCs in the active condition at T2 – Experiment 1

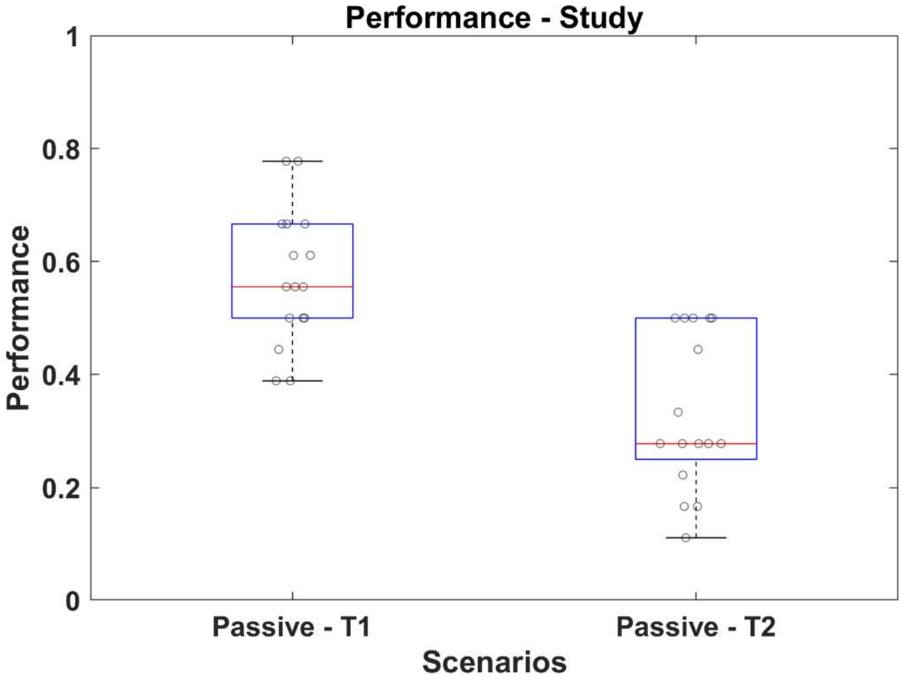
6.2. Experiment 2



Semantic clustering scores in active and passive conditions in T1 and T2 – Experiment 2



Performance in active condition in T1 and T2 – Experiment 2



Performance in passive condition in T1 and T2 – Experiment 2

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8. Appendices

8.1. Appendix 1 – Voice over script (English)

Tutorial Intro:	Welcome to Nozama. At Nozama we aim to become the best delivery centre in the world, and you can become part of our journey! Before we can hire you, we must conduct some training sessions on your hability to position boxes and memory of items. You will have to carry boxes from the delivery truck behind you to the delivery area painted on the floor. Every time you grab a box, an item image will appear on top of it for 3 seconds and some random placement options will appear on the ground. You must place the box in one of them. After you carry ten boxes, the training session wil end. If you have any doubts, now is the time to ask. Start after you hear the buzzer. Good luck!
Tutorial Outro	Good job! You are one step further to becoming an expert delivery person. You will now proceed to more complex training scenarios, in which you will also be tasked to memorize the images of items contained inside the boxes.
Active Intro	On this training scenario, you must grab the boxes from the delivery truck and place them in the delivery area. You are tasked to memorize all the items contained in the boxes, so pay special attention. After placing 18 boxes, this training scenario will end.
Active Outro	Congratulations! You have successfully placed 18 boxes. You will now proceed into a recall session in which you'll be asked to remember the items and say them out loud. The screen will go black, so there are no distractions.
Passive Intro	At Nozama we always try to stay ahead in technology. On this scenario, you must grab the boxes and carry them to the sorting robot. The robot will then deliver the box to the position it sees fit. Pay attention to it and ensure it delivers all boxes correctly. New boxes will only appear when the robot returns to its origin position. You are tasked to memorize all the items contained in the boxes, so pay special attention. After placing 18 boxes, this training scenario will end.
Passive Outro	Congratulations! You have successfully placed 20 boxes. You will now proceed into a recall session in which you'll be asked to remember the items and say them out loud. The screen will go black, so there are no distractions.

Recall Intro	On the previous scenario, there were 18 boxes which displayed an image of the item they hold. You will now have 90 seconds to try and remember all of them. If you don't know how an item is named, try to describe it briefly. Ready? Start when the hourglass disappears.
Recall Outro	The recall session is now over. Thank you!
Conclusion	Thank you for participating in our training sessions. Nozama is proud of you! You will hear from us shortly! You may now remove the head mounted display.

8.2. Appendix 2 – Script Pre-Trial Ethics (English)

Experiment Script:

Good Morning/Good Afternoon,

First of all I would like to thank you for coming and giving a bit of your time for this.

You will be participating in an experiment conducted for a Master Thesis on the Masters Degree on Cognitive Systems and Interactive Media.

It is an experiment conducted inside a Virtual Reality Environment. There is no fear, terror nor abrupt movements or dizziness, so don't worry, it is in fact a rather mundane task which will have you walking through this space.

There is a virtual grid-wall which will tell you when you are getting too close to a real, physical wall, so don't be afraid to hit or trip on anything, the space is 100% clear and controlled.

At any point if you wish to stop the experience, simply raise your hand and tell me.

There are only two buttons of the controller you must know:
The trigger, just at the start, to write on a digital keyboard. Point and click. Easy.
The grab button. You will be tasked with grabbing some objects. To do so, with only one hand, place it inside said object and press the grab button. If you stop pressing it, the item will fall, and you will have to pick it up again. To place it where desired, simply stop pressing the grab button.

You will hear a robot voice giving you instructions. Do anything she asks for. (It will be nothing crazy).

Some data will be gathered from this experiment. Especially regarding movement.
The only piece of identifiable data which will be gathered is your cell phone number. At any point you can request to delete your data.

If you are okay with it, I would also like to videotape the experiment, just as a backup.

After the experiment is concluded, and the due analysis of the data is conducted, all personal identifiable data will be deleted.

Do you have any doubts?

Inside the app, you will have to press a button which will certify you have been briefed about the experiment and the corresponding data collection.

Let’s put the headset on.

You will be inside a menu. Do not click anything before I say so.

Click on the ID bar and write down your ID number.

Check it is correct and press enter.

By pressing the accept button you agree to continue the experiment and the necessary collection of data.

8.3. Appendix 3 – List of Items for Experiment 1

1	accordion
22	bed
26	belt
53	chair
67	couch
70	cup
78	dress
79	dresser
80	drum
92	flute
97	fork
101	pan
104	glass
111	guitar
114	hammer
117	harp
118	hat
127	kettle
132	lamp
162	pants
168	pencil
171	piano
176	pliers
190	roller
192	ruler
196	saw
198	screw
199	screwdriver
203	shirt
204	shoe
211	sock
218	stool
219	stove
226	table
228	television
232	tie
234	toaster
243	trumpet
248	violin
259	wrench

8.4. Appendix 4 – List of items for Experiment 2

14	ball	91	flower
16	banana	93	fly
39	bus	97	fork
45	cannon	111	guitar
48	carrot	146	moon
53	chair	196	saw
59	cigarette	211	sock
73	dog	239	stoplight
86	eye	257	win