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***Memory Integration - fundamental feature at a cost?
An EEG study.***

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Abstract

This study investigated whether integrative encoding in an associative inference paradigm (AIP) using naturalistic narrative videos to present the stimuli, comes at cost of memory specificity by testing source- and details-memory of the presented videos and measuring electroencephalography (EEG). Based on earlier work (e.g. Carpenter et al., 2017), it was expected that integrative encoding in the form of memory generalization measured via an associative inference test would be related to lower memory specificity. Furthermore it was hypothesized that potential effects found in the neural data during encoding would be related to memory specificity. The behavioral data of N = 37 participants were analyzed using ANOVAs and the neural data by computing event-related-potentials (ERPs) and time-frequency representations (TFRs). It was revealed that there was no cost in terms of lower memory specificity due to integrative encoding. Trials related to associative inference revealed no significant difference from control trials. Trials related to unsuccessful associative inference resulted in higher memory specificity than the control. During the encoding phase, integrative encoding was demonstrated by significant effects in the TFRs, but this could not be related to the behavioral data. These results suggest the involvement of integrative encoding and parallel separate storage of item-related memories and thus flexible retrieval.

Keywords: Integrative Encoding, Memory Generalization, Associative Inference, EEG, Event-Related Potentials, Time-Frequency Analysis, Memory Integration, Flexible Retrieval, Memory Specificity

Everyone has experienced a similar situation, but put yourself into this one: You've moved to a new part of town, and for the first time you go to the coffee shop around the corner to buy a bagel. On your visit you see a man there with a little girl. You conclude that it is father and daughter. Another day you decide to try out the greengrocer two streets away. On your way into the store, the little girl comes bouncing out of the shop, but there's no sign of her father. Instead, a somewhat older woman comes after her. You haven't seen the woman yet, but you know immediately that she knows the child's father. Maybe she is his mother or mother-in-law? Although you have never seen the man and the woman interact and have no evidence to support this conclusion, you will connect the man and the woman in your mind. This is possible thanks to memory, in particular, generalizing memories thanks to memory integration.

Memory

Memory broadly speaking is saving information to later use in order to function in this world. Without memory there would not be learning, without learning no cognitive development. There are two types of memory: semantic and episodic. Semantic memory can be summarized as factual knowledge. Episodic memory is often referred to as “mental time traveling” (Tulving, 2002) since it can be experienced as mentally going back to an episode lived through a long time ago and memory is even necessary to imagine the future (Schacter et al., 2012; Schacter & Addis, 2007). Both semantic and episodic memory are subject to three underlying processes: encoding, storage, and retrieval. Encoding refers to a process that brings the information into the brain, usually via sensory input (e.g. seeing the man with the girl, hearing them talking to each other) and then transforming this sensory input into a kind of information the brain can work with. Storage then is the process that makes sure that no information will get lost and that it will be ‘saved’ in a logical context. And retrieval is the process of pulling that information from the “memory storage” to work with it, to think, really. In our example you encoded that the man belongs to the girl. This information was stored and when you saw the girl coming out of the door of the greengrocer’s store, you retrieved this memory of her being with the man, which

then leads to making it possible that you notice that he was missing and something was different to when you last saw the girl.

According to the neurobiological rooted cortical reinstatement model (CRM), at retrieval of a memory, the same processes that were active during encoding will be reactivated, such as you don't just "relive" through the experience, but the brain actually does the same thing again (Norman & O'Rilley, 2003; for reviews see Kent & Lamberts, 2008; Tambini & Davachi, 2019; Thakral et al., 2015; Xue, 2018). Consistent with this, the cognitive-psychological rooted transfer-appropriate processing (TAP) account hypothesizes that successful retrieval of an episodic memory depends on the degree to which the retrieval process triggered by a cue for the then retrieved memory overlaps with the process of encoding that memory (Morris et al., 1977; Rugg et al., 2008). As with CRM, it is postulated that the same cortical patterns are engaged in memory retrieval as were engaged in encoding. Bramão and Johansson (2018) found neural evidence for the TAP-account, as in their study using electroencephalography (EEG) they observed the reinstatement of the same neural patterns that were measured during encoding being active during retrieval.

Many different brain areas are involved in memory. Of course, all areas that receive and process sensory information are a substantial part of memory, feeding the memory machinery with input. But memory content can also be created without sensory input from the outside, as when one makes up a story (e.g. our father-daughter example from the beginning). The core of the memory machinery is primarily made up of the medial temporal lobe (MTL), the prefrontal cortex (PFC), and various cortical areas (Schlichting & Preston, 2015; Fernandez et al., 2022). For episodic memory, the Hippocampus (HC), a part of the MTL, is assumed to basically manage the memory system. While the memories are stored in cortical areas, the HC is majorly involved in comparing and differentiating incoming new memories and basically takes care of the organization and order of incoming information. It creates memories by binding the information into representations during encoding and during retrieval it is responsible for pattern

completion (Dickerson & Eichenbaum, 2010; Ekstrom & Ranganath, 2018; Kumaran & McClelland, 2012; Rugg & Vilberg, 2013; Schapiro et al., 2017; Shohamy & Wagner, 2008; Zeithamova & Preston, 2010).

On the neural level, brain activity can be measured using functional magnetic resonance imaging (fMRI), a technique offering a high spatial resolution, and EEG, offering a high temporal resolution. There are different frequency thresholds that can be differentiated with an EEG: delta waves (~1 - 4Hz), theta waves (~4-8Hz), alpha waves (~8-12Hz), beta waves (~12 - 30Hz) and > 30Hz gamma waves (Crone et al., 2011; Tsipouras, 2019). According to the Synch/DeSynch model (Parish et al., 2018), desynchronization of alpha waves in the neocortex predicts successful memory encoding and retrieval, while theta wave synchronization of the HC happens when engaged in learning. The model explains this as neurons in the neocortex need to break out of alpha oscillation to represent input - hence they desynchronize. And that in the hippocampus neurons firing at theta level relates to the emergence of memories - hence they synchronize. Research found evidence that hippocampal theta and gamma synchronization (Fell & Axmacher, 2011) and cortical alpha and beta desynchronization (Hanslmayr et al., 2012) both play an important role for memory encoding and retrieval. It is suggested that hippocampal theta synchronization acts as a mediator for establishing concepts and neocortical alpha desynchronization happens due to those established concepts becoming active (Parish et al., 2018). According to Jensen and Mazaheri (2010) and Staresina et al. (2016), successful encoding and retrieval is related to cortical alpha power decreases, meaning desynchronization. Hanslmayr et al. (2012) and Waldhauser et al. (2016) published comparable findings.

The function of memory goes far beyond simply remembering facts and experiences from the "yesterday": it is indispensable for learning from such experiences for the "tomorrow" and also for imagining future events to predict and evaluate possible outcomes and consequences of these (Schacter et al., 2012). Memory is also indispensable for the "now": it is important for finding one's way in the world, not only purely in terms of spatial orientation, but

also in a socio-cultural context. It has long been recognised that parts of cognition rely on episodic memory, peculiar on the memory mechanisms of the HC. One example is that basic processes of reasoning would not be possible without a functioning memory (Chun & Phelps, 1999; Rickard & Grafman, 1998). Another example is memory specificity, meaning the extent to which memories are accurate and can be contextualized in particular ways, such as in terms of time, place, or relationship. It is known that this function is based on episodic memory and is controlled by the HC (Squire & Zola, 1998). Regarding our example: without memory, neither the conclusion that the man and the girl are father and daughter, nor the later logically founded connection between the woman and the man would be possible. Here, the HC's suggested function of pattern completion comes into play: several papers suggest that the HC is also responsible for generalization mechanisms between memories (Eichenbaum et al., 1999; Kumaran & McClelland, 2012; Staresina et al., 2016; Zeithamova, Schlichting, et al., 2012).

Between both memories from our example there is an overlap: the girl. As an overlapping part of both memories, the girl in the greengrocer serves the brain as a cue to the earlier memory, hence relating the man and woman to one another. Studies have shown that this type of memory overlap can, when encoding the new memory, in fact serve as a cue for reinstatement of the associated prior memory and related with making a novel generalization between the man and the woman (Kuhl et al., 2010; Zeithamova, Dominick, et al., 2012). When you then saw the woman, you added new information to the girl and her dad and basically gave this memory an update, the new memory led to altering the old one. This is what is called memory integration. Memory integration, thus recognizing similarities between two memories and generalizing them, has been a vital topic of scientific discourse (e.g. Preston et al., 2004; Shohamy & Wagner, 2008; Zeithamova, Dominick, et al., 2012). But what exactly happens when, thanks to the overlapping of two (or more) memory contents, they get associated with each other? What is the underlying process of memory integration?

Memory Integration

Memory integration: “the ability to link information across related experiences”, as Bowman et al. (2021, p.1) summarized it, is one of the fundamental functions of memory and yet are the underlying processes of this phenomenon not very well understood. So far, there is no broad consensus on how exactly and when in the memory process it happens. What is clear is that memory integration happens when, when experiencing an event, aspects of that experience are sufficiently similar to an earlier event to serve as a cue for the brain to retrieve that prior event. The new and old memories are then linked. But how does this happen? Many studies use associative inference paradigms (AIP) to investigate this question. AIPs present participants with overlapping item pairs (AB and BC) which later allow to see relationships between items that have not been presented together (AC). Richter et al. (2016) demonstrated that the state of the brain during integration is significantly different from the state during regular encoding and retrieval. Thus, the brain takes in new memory content, matches it with earlier ones and classifies, while the overlapping portions of memories provide a clue to belongingness and context (Gershman et al., 2013; Schlichting & Preston, 2015; Zeithamova, Schlichting, et al., 2012; Zeithamova & Bowman, 2020). Presenting stimuli in form of stories, Cohn-Sheehy et al. (2021) found that the patterns of HC activity captured with fMRI were more similar for events forming a narrative presented with long time delay than events not forming a narrative but being presented with a similar aspect. So the HC seems to integrate events that form a narrative, creating a bigger picture, rather than those being presented together and sharing some aspects of the story. Quite a useful system for navigating this complex world.

What we know about the underlying mechanisms

The HC is considered one of the main actors of memory integration: it interacts with the ventromedial prefrontal cortex (VMPFC) to relate the now newly experienced events to already encoded experiences and generalizes across those memories (Bowman & Zeithamova, 2018; Eichenbaum et al., 1999; Kumaran & McClelland, 2012; Schlichting & Preston, 2015; Staresina

et al., 2016; Zeithamova, Dominick, et al., 2012). On the neural level, it was found that theta oscillations are related with associative memory (Herweg et al., 2020) and that hippocampal theta waves while encoding “predict subsequent memory integration” (Backus et al., 2016). Hasselmo et al. (2002) suggested that, during alternating encoding and retrieval phases, theta oscillations manage information flow. And Staresina et al. (2016) found that alpha power decrease during recollection is linked to hippocampal pattern completion, or generalization. Generalization is a fundamental part of memory integration. But the exact mode of action of this mechanism is not yet entirely elucidated. So, to form a connection between the man and the woman, generalization is needed. It is possible that during encoding of a new memory, the overlap with a prior one causes that a relationship between both memories is learned. This possible mechanism is called integrative encoding. Another possibility is that the process of generalization occurs at retrieval, when needed, called flexible retrieval. One aspect literature has generally agreed on, however, is that generalization can be assumed to potentially come at the cost of memory quality (Carpenter & Schacter, 2017, 2018a, 2018b; Gershman et al., 2013). But, how do generalization and thus integration come about, is it due to integrative encoding or flexible retrieval? And what is known about the costs?

Integrative Encoding.

The integrative encoding approach assumes that the process of generalization, which enables the integration of memories, occurs during the encoding of the subsequent event. In the example from earlier, this would mean that once you see the woman with the girl, you will immediately think of the earlier memory of the man with the girl and integrate those memories. So in this account, the HC is assumed to generalize and mnemonically link those events as soon as two or more memories are overlapping, during the encoding of the latest memory. It is assumed that not only the events get encoded, but also the knowledge about the relationship between these memories will be encoded (Eichenbaum, 2000). Shohamy and Wagner (2008) produced results in their fMRI study suggesting that representations remain separate, but in

case of overlap will be connected to then make generalization possible. Their study is a strong argument for integrative encoding. A study published by Kuhl et al. (2010) suggests that activity in the HC during encoding of new memories predicts retention of memories of earlier, related events. Schlichting et al. (2015) used fMRI and according to their study, the posterior HC and anterior MPFC maintain distinct memories for individual events while at the same time the anterior HC and posterior MPFC integrate across memories. They conclude that their results are more likely to be explained by integrative encoding. Zeithamova, Dominick, et al. (2012) presented a study demonstrating evidence that earlier memories are reinstated during the retrieval of novel related events, also advocating for the account of integrative encoding.

Flexible Retrieval.

Generalization across overlapping events does not necessarily require integrative encoding. Other accounts in the literature suggest that generalization can occur when needed thanks to flexible retrieval. Accordingly, the HC will retrieve and flexibly connect and generalize over overlapping memories on demand. In our example, you would not yet combine the memory of the girl with the man and the woman automatically once you see the woman, but for example when you see the girl alone in the street and think of how you have seen her with her father and also the woman. In a solely behavioral study, using a version of the AIP, Banino et al. (2016) with their data created computational simulations which suggested that generalizing occurs “on the fly”, so to speak, during retrieval rather than encoding. Assuming inferential retrieval and also using an AIP, Carpenter and Schacter (2017), in an again behavioral study, were interested in whether contextual details were assessed before or after generalization. In four experiments they manipulated different aspects of the AIP: additionally to testing the link between A and C, they also changed the context in which the item-pairs were presented and controlled for the moment of detail testing: before or after associative retrieval. Their data showed that for trials of successful inference the memory specificity for the contexts was lower compared to trials of unsuccessful inference. Since according to their paradigm integrative encoding should have

produced more false memories for successful than for unsuccessful inference trials before the associative inference test and they could only find this effect after the test, their work speaks in favor of flexible retrieval. A later study (Carpenter & Schacter, 2018b) also produced data that hints more into the direction of the flexible retrieval account. Sanchez and Zeithamova (2020), using a purely behavioral approach of data collection, presented participants with two stimuli that share one common association stimulus or require the same reaction of the participant. Hypothesizing a cost of source memory coming with integrative encoding, they found stronger evidence for integrating mechanisms during retrieval than during encoding, but no evidence for source memory being a cost for integrative processes in this kind of paradigm. Carpenter et al. (2021), again using a type of the AIP, examined the extent to which memory integration is related to false memory. This time, they collected neural data using fMRI. They found evidence that memory integration in flexible retrieval is associated with memory loss regarding the details of the scenes learned. The neural data revealed involvement of the anterior hippocampus, posterior medial prefrontal cortex, and left inferior temporal gyrus in associative inference.

Overall, the work on the mechanisms underlying memory integration does not seem to point in a clear direction between integrative encoding and flexible retrieval. There are also studies that could be interpreted in a way that suggests both integrative encoding and flexible retrieval play a role in memory generalization. Chang et al. (2019) trained children in math problem solving, collecting neural data via fMRI. Here, memory integration was operationalized in terms of strategy-transfer. The participants were expected to detect similar calculation task styles to generalize and transfer the learned strategies. Results suggest that in general the children performed more efficiently on the trained problems. Those who learned fast, showed better performance both on trained and novel tasks and they could recognize new and learned problems better. This suggests stronger integration. The neural data reveals that the fast learning children show more similar neural representations between new and trained tasks and that they use different functional brain circuits for trained and novel tasks. Altogether, this study

supports an account that suggests that both integration as in integrative encoding and separation and combining on demand as in flexible retrieval take place in parallel. Even Shohamy and Wagner 's (2008) study, widely interpreted in the light of integrative encoding, does not argue for flexible retrieval to be impossible. Zeithamova and Preston (2010) also left the possibility of both mechanisms playing their own important role in memory integration open for discussion. There is not enough evidence to agree on what kind of relationship there is between integrative encoding and the update of memories. What is broadly agreed on is how fundamentally important memory generalization is for cognition. It is essential for inferential reasoning (Varga et al., 2019; Zeithamova, Schlichting, et al., 2012), helpful for decision making (Shohamy & Daw, 2015) and knowledge expansion and associative learning (Varga & Bauer, 2017). It crystallizes that there may well be costs associated with generalization (Carpenter & Schacter, 2017, 2018b; Sanchez & Zeithamova, 2020; Zeithamova, Schlichting, et al., 2012), but Kuhl et al. (2010) for example found the opposite, that the HC in fact uses new related memories to maintain older ones.

Consequences of Memory Generalization.

The previously described study by Carpenter and Schacter (2017) shows that a consequence of generalization across overlapping events is the loss of memory specificity for the individual events. However, these findings are not consensual. For example, Banino et al. (2016) found that the participants' ability to generalize was related to lower memory performance about the single events. Particularly strong generalization ability on the other hand resulted in better memory performance for the events serving as a basis for generalization. The results were related to slower reaction times (RT): Trials that required associative inference took longer than direct associations. The particularly strong generalization ability was accompanied by higher response times. However, there is little neural data addressing the possible trade-off between memory generalization and specificity. Only two studies used fMRI to address this question (Carpenter et al., 2021; Chang et al., 2019). In these previous studies, the authors

have found that AC associative inference comes at the cost of memory specificity. However, the authors found little evidence for memory integration processes and their studies focused on flexible retrieval. For this study a paradigm was designed that promotes integrative encoding to investigate the consequences of memory generalization based on integrative encoding mechanisms on memory specificity. In addition, study designs with classical AIPs have mostly been very abstract in nature. The tasks use typically single words or objects, often regardless of their 'natural' appearance in the world, without any context. However, the world we live in is far more complex and a function of memory that is so fundamental to so many higher cognitive processes should be studied in a more real-world paradigm to really get to the bottom of how memory integration affects experience and behavior.

The Current Study

Aims and Significance

This study aspires to cover the shortcomings of previous research summarized above. In this project I aim at investigating the relationship between integrative encoding mechanisms and memory specificity. The project is meant to test memory associations and memory specificity for the content of scenes shown in the form of videos to investigate a possible cost of memory integration. The stimuli were presented in the form of human-like characters interacting with each other in narrative videos in different settings. Leaning on a classical AIP, in the first encoding phase character A will first be presented alone, then interacting with character B. In the second encoding phase, a character C will be presented alone followed by interacting with B, too. In the retrieval phase, the associations of AB, BC and, most importantly, the associative inference for AC pairs will be assessed. It will then be examined how the correct or incorrect associative AC inference will have an impact on memory for the source of these inferences and memory of details of the videos. Additionally, it will be examined to which extent EEG data patterns that occur when viewing the BC-videos leading to memory inferences of AC-pairs in the association test, will be related to later performance of the source- and details-memory tests.

The source memory test will investigate if participants can remember not only the associative inference between A and C, but also that it is an *indirect* association (in contrast to the direct associations AB and BC). The details-memory tests have only been used once before by Carpenter et al. (2021) in this kind of paradigm and will test the memory specificity for two different aspects of the scenery of the presented items. The items of the associative inference test (AIT) will be presented embedded in videos, because this aims to mimic a more realistic setting and makes a highly ecologically valid paradigm possible. There will also be a control variable, pair XY, which will be presented during the second encoding phase, serving as a good contrast to the BC-videos, as it will not trigger any reactivation as expected for the BC videos when presenting B. Cohn-Sheehy et al. (2021) used a paradigm with narratives in the form of spoken stories to test the function of the hippocampus in memory integration. The video stimuli in the current project also represent a kind of narrative, albeit not in the literary sense. This project is the first to investigate the possible trade-off between integrative encoding and specificity using neural data measured via EEG and almost life-like stimulus material in the form of narratives.

Research Questions

The question that primarily motivates this work is:

Does integrative encoding measured with an AIT occur at the expense of memory specificity for the source of the tested associative inferences of AC pairs and the details of the encoded events?

Hypotheses

Hypothesis 1

If integrative encoding has an impact on memory specificity, then it is expected that the performance of the source-memory test and the details-memory tests will be lower for trials related to correct associative inference of AC compared to those related to incorrect associative inference of AC.

Hypothesis 2

It is expected that neural patterns associated with integrative encoding during BC learning will be predictive of the source- and details-memory tests.

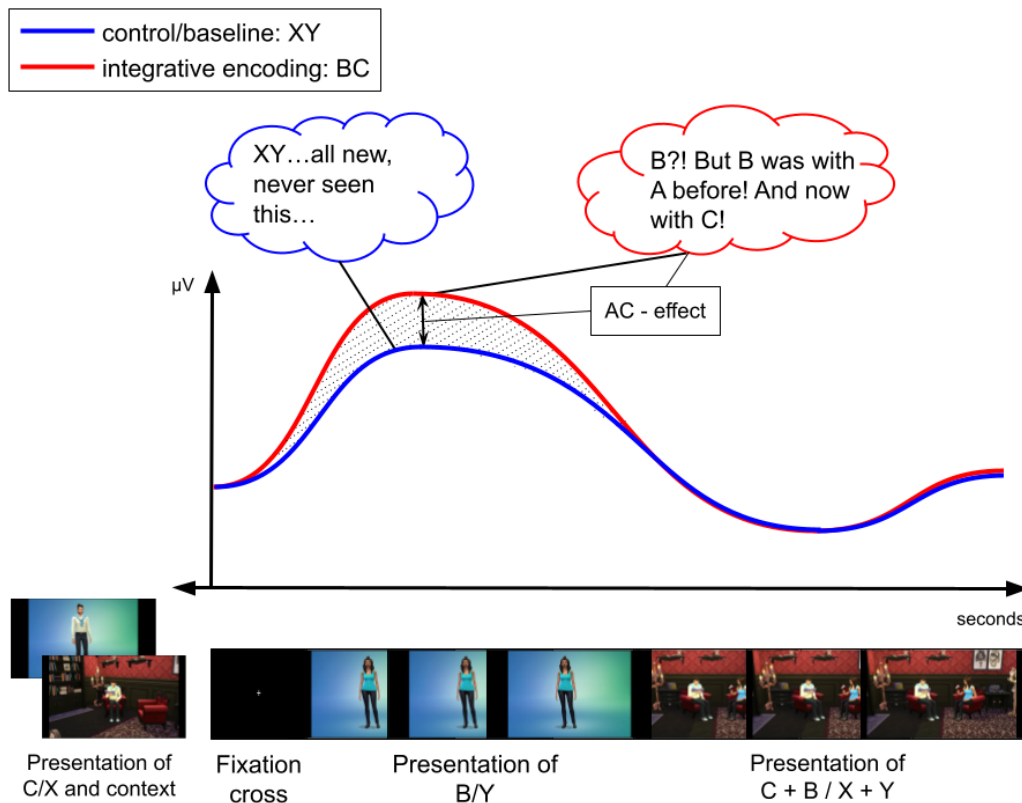
H2.1: there will be an effect of significant difference in neural activity for BC vs XY videos due to the reactivation of the AB-video during video BC, potentially revealing the neural correlates of integrative encoding (see figure 1 for illustration).

H2.2: If this effect is associated with integrative encoding mechanisms, important for memory generalization, then the effect will be predictive of inferential AC associations

Additionally, if integrative encoding mechanisms result in a loss of memory specificity then the effect will correlate negatively with memory for the source of the associations (H2.3) and with the memory for the details of the videos (H2.4).

Figure 1

expected neural effect during the presentation of BC-videos in contrast to XY-videos



Methods

Participants

Participants were recruited via convenience sampling by publishing posts with information about the study in local social media communities (Facebook). The target size of subjects, considering the relatively high exclusion rate in this type of study, was set at $N = 40$. This was to ensure that the data sets of at least 24 subjects could be considered in the analyses after data cleaning and preparation. The minimum sample size was decided on the basis of previous studies using comparable designs (Banino et al., 2016; Carpenter et al., 2021; Schlichting et al., 2015; van Kesteren et al., 2020, Varga & Bauer, 2017). In total, 41 individuals participated in this study. Each participant gave written informed consent to take part. Different subsets of the data were used for the analysis. For checking the behavioral data, a subsample of $N = 37$ participants was used. One participant had to be excluded as they scored 100% in condition AC of the association task and at least one incorrect inferential trial was needed to conduct the planned analysis. Three participants' EEG data was too noisy to be used at all. Of this subsample, 76% identified as female ($n = 28$) and 24% identified as male ($n = 9$) with a mean age of 24.3 years ($SD = 2.94$). For the analyses planned to compare trials leading to successful and those leading to unsuccessful inferential associations, a subsample of $N = 29$ subjects, of which 76% identified as female ($n = 22$) and 24% identified as male ($n = 7$) met the inclusion criteria, meaning their data contained at least 10 trials of both correct and incorrect AC-associations. The sample of ages ranging from 19 years to 35 years ($mean = 24$, $SD = 2.99$) consisted of mostly students of 13 different nationalities. Hence, the whole experimental procedure was conducted in English. As compensation for taking part in the study, all participants received a 200 SEK voucher from a national book seller or one to be used in various online shops.

Inclusion Criteria

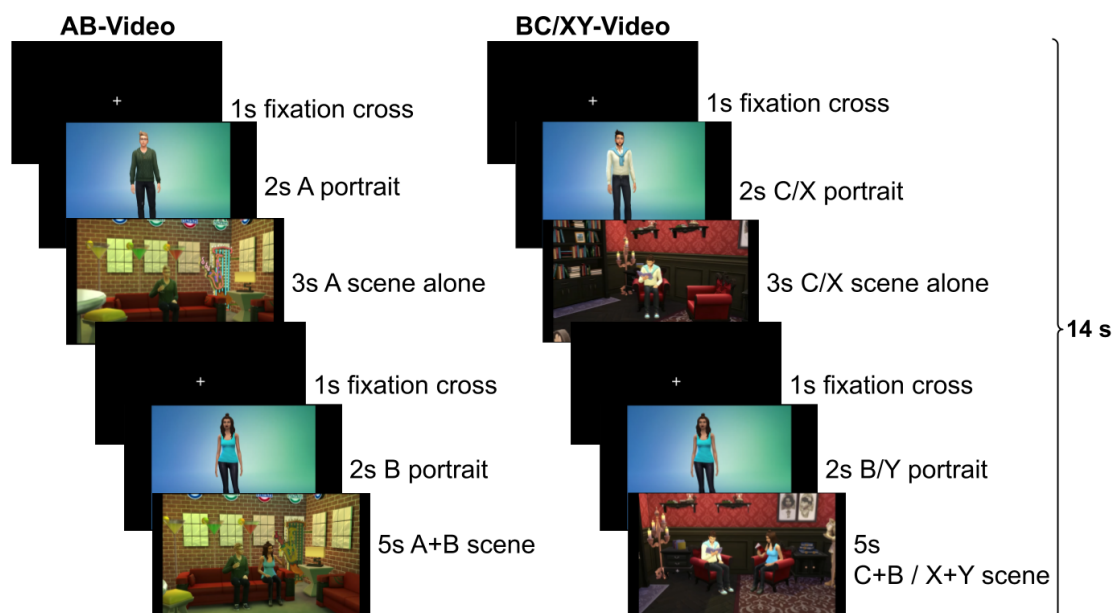
To be considered eligible for participation in the study, participants had to speak and understand English fluently, should not be suffering from symptoms of any diagnosed psychiatric disorder, have normal color vision and feel healthy and well rested.

Material

The experiment was set up like a classic associative inference task, but with stimuli presented in a vivid context in video. Compared to a classic associative interference test, the stimuli in this design were presented in the form of the Sims A, B and C interacting in the videos. There were four different types of stimuli: videos, face pictures, scene pictures and outfit pictures. The videos were generated using the life-simulation game The Sims 4 by Electronic Arts (www.thesims4.com), in which two individuals (called “Sims”) were interacting with each other. To create the video narratives using this video game was inspired by a study by Milivojevic et al. (2015). The videos were organized in stories, each story containing two videos. A video would always last 14 seconds (see figure 2).

Figure 2

Overview of video concepts.



In the first video (AB), a full-body picture of Sim A was presented (for two seconds), then a video of Sim A in scene A (three seconds), followed by a full-body picture of a Sim B (two seconds) and a video of both Sim A and B interacting in scene A (five seconds). The second video of the story (BC) was organized following the same concept, this time instead of Sim A in scene A, a Sim C in scene C was shown, then accompanied again by Sim B. A third video (XY) would serve as control: Here Sim X was shown in scene X, followed by Sim X accompanied by a Sim Y. There were 50 of these stories, two of which were used to train the experiment concept in the instruction part of the experiment.

To test the associations, pictures of only the faces of Sims were presented with two Sims to choose from, one being associated with the Sim in question and one not (fig 3A). The source memory test was directly following the related association test item and consisted of the simple question "Did they appear together?" (fig.3A). Both the association test and the source memory test consisted of 96 items. To test for details of the presented scenes, pictures of the scenes exactly as shown in the video were taken (without Sims present), then these scenes were slightly altered by changing the wall and floor colors using the build-mode in the video game. At test, the head of a Sim A or C/X was presented and four scenes were shown to choose from: the correct original scene, the altered version of the correct scene and an incorrect original scene from another video (either from the corresponding AB-story or, for controls XY, a story of another XY video) and an altered version of this incorrect scene (fig. 3B). Each participant answered 72 room-memory test items. To test for details of the presented Sims, the full-body pictures presented in the video were shown in four versions: the original version and three identical pictures with the Sims wearing the same outfit in another color for the top clothing (fig. 3C). 120 such items were answered by each participant. After every single memory test item, a confidence check took place ("How confident are you about your answer?").

Figure 3

Example items for memory test categories.

A: Block 1: associations + sources

How confident are you about your answer?
1 - guessing

Did they appear together?
1 - yes 2 - no

How confident are you about your answer?
1 - guessing 2 - maybe 3 - sure

B: Block 2: details - rooms

How confident are you about your answer?
1 - guessing 2 - maybe 3 - sure

C - Block 3: details - outfits

How confident are you about your answer?
1 - guessing 2 - maybe 3 - sure

Note. This presents the four memory test categories with a confidence check for each. In the instructions, a clear explanation on how to handle these was provided.

Procedure and Design

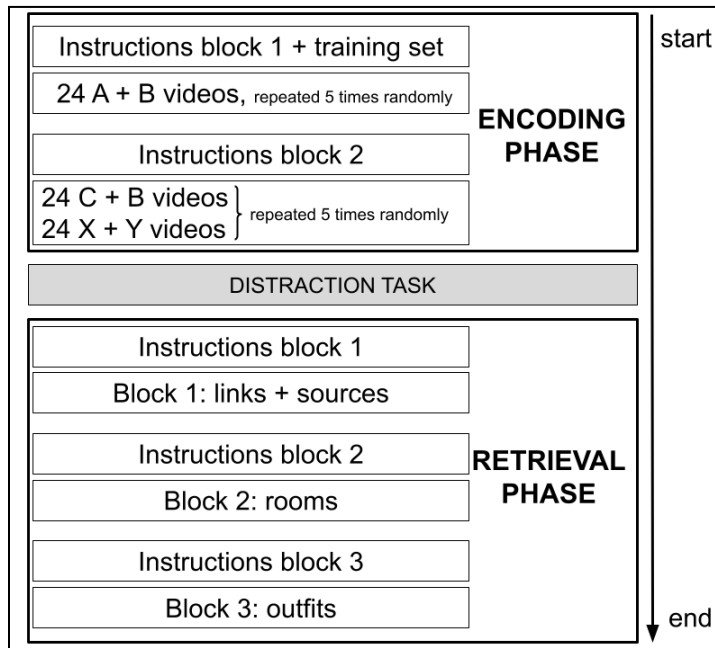
Procedure

Entering the lab, participants were introduced to the facility and briefed about the preparations by one of the two experimenters. They were explained the EEG-cap and preparation procedure briefly as well as shown the faraday-cage they would spend the experiment in. A participant information sheet had been sent via email to them prior to the scheduled time, and they also could read a hard copy in the lab before signing the participant informed consent form. Then, the EEG-cap was mounted. The participant was then moved to the stimuli computer in the faraday cage. On the stimuli computer, the experiment was run using PsychoPy (Peirce, 2007).

First, a detailed instruction took place with three training videos (AB, BC and XY) and a source memory test as an example. In the instructions, only the association- and source memory tests were mentioned. The details-memory test was not mentioned to not bias the attention of the participants towards the details instead of the links. Then, in the two encoding phases, the videos were shown. After the encoding phases, a distractor in the form of a mathematical task took place ("Please count down in steps of 7 from the number presented on screen"). Then the source memory test was performed, followed by the details-tests (first rooms, then outfits). EEG data was collected during the whole experiment, but only part of the data collected during the second part of the encoding phase was used for this study. See figure 4 for a schematic overview of the experimental procedure.

Figure 4

Overview of experimental design.



The experiment consisted in two different phases: an encoding and a retrieval phase. In the encoding phase, participants watched the video material on a computer screen. The videos were shown in two encoding-phases and there were two set-ups of the encoding phase, to control for non-specific stimulus effects of the video content. In the first phase, participants would see 24 AB videos. In the second phase, 24 BC and 24 XY videos were presented. In total, each participant was presented with 120 Sims (24 of each As, Bs, Cs, Xs and Ys) and 72 different scenes (24 As, 24 Cs, 24 Xs). Within each phase, videos were repeated five times in mini-blocks of 12 videos in random order in each repetition cycle. There was an option for the participants to take a break after 15 videos and between encoding phase 1 and 2. In addition, one of three attention-check videos were played at random intervals. These showed a Sim in a blue tracksuit jogging in a green neighborhood. The subjects were asked to press a certain button each time they saw the jogger in order to control their attention.

After a short distraction task, the retrieval started which was organized in three blocks. The retrieval phase of the experiment contained four categories of memory tests. The participants were instructed to answer the questions as quickly as possible, following their initial intuition. In the first block, to test memory of the association of Sims, the stimuli were presented as described earlier and the participants could enter their answer on which of the two Sims in the lower row was associated with the Sim on top by pressing the key corresponding to their choice on the keyboard (Fig. 3A). They were then asked for their confidence regarding their given answer ("How confident are you about your answer?") on a three-point-scale (1 - guessing, 2 - maybe, 3 - sure). To test for the source memory, the participants were then asked if those Sims were associated directly or indirectly ("Did they appear together?" 1 - yes, 2 - no), followed again by the confidence question. As mentioned, the following part of the memory tests was not expected by the participants. The second block tested memory for the scene-related details by asking for the correct room, each question again followed by a confidence check (Fig. 3B). The last block tested the Sims-related details, their outfits. Again, the face of a Sim and the stimulus material was presented and each question was followed by a question of confidence. After the experiment the participants were debriefed and got an opportunity to ask questions before handing over the compensation.

Ethical Considerations

This study was planned and conducted in accordance with the Swedish Act concerning the Ethical Review of Research Involving Humans (2003:460, Swedish Research Council, 2017). The procedure of EEG is non-invasive, not physically harmful, does not involve pain and no physical intervention took place. No sensitive information or biological materials from the participating individuals were collected as part of this study. The stimulus material did not show any kind of potentially triggering content, as no violent or sexual scenes and/or contexts were presented. All participants were informed about the procedure prior to the experiment and it was

made clear that they would be able to stop the participation at any given time. Furthermore, every participant signed a document of informed consent (see Appendix B).

EEG Recording, Data Preprocessing and Preparation

To record EEG, a SynAmps RT Neuroscan 64-channel amplifier (sampling rate 1kHz, bandwidth DC-3500Hz, 24-bit resolution, left mastoid reference) with 62 electrodes attached to an elastic cap (active electrode EasyCap) was used. The cap was placed according to the extended 10-20 system. Furthermore, an electrode was attached to the skin under the left eye of the participants to detect and later filter noise caused by eye blinks. It is to note that electrodes C2 and C4 did not work during most of the experimental sessions due to material defects.

To preprocess the data, the files were downsampled to 500Hz and epochs of 8 seconds were created, each representing the second part of the video clip plus 1 second prior to the onset of that part of the video clip (see fig. 6). It then was preprocessed using FieldTrip (Oostenveld et al., 2011), a matlab-compatible toolbox and in-house matlab scripts. The data was transformed to a linked-mastoid reference and baseline-corrected by subtraction with the average amplitude of the epoch. The data was also corrected for eye-blinks and -movements using the electrode placed under the left eye and Fp1 in the cap for blinks and Fp9 and Fp10 electrodes in the cap to detect horizontal eye movements in the data. The data was then manually viewed and checked. Epochs showing signs of any more muscle- or eye movement related and other artifacts were removed. An independent component analysis was applied to detect and remove components showing eye artifacts and muscle activity other than from the EEG signal. Finally, if there were, channels showing constant noise across participants were excluded from the analysis or interpolated. Another manual viewing of the data took place for a final removal of trials with residual artifacts. The data cleaning resulted in a mean trial number of $M = 107.83$ BC-trials ($SD = 23.59$) and for $M = 107.43$ XY-trials ($SD = 23.8$) for the subsample of 37 participants. For the subsample of 29 participants it lead to $M = 46.13$ BC-trials leading to

correct AC-inference (SD = 18.19), M = 38.27 BC-trials leading to incorrect AC-inference (SD = 18.36), M = 56.08 XY-trials leading to correct inference (SD = 22.04) and M = 26.62 XY-trials leading to incorrect inference (SD = 20.85).

Data Analysis

To clean the data, the reaction times (RT) of the participants were analyzed. Answers with times > 10 seconds were re-coded to 'incorrect' to prevent responses based on logical reasoning rather than intuitive memory recall from biasing the results (8.2% of overall trials). Also, trials in which the confidence question was answered with '3 - guessing' were re-coded to 'incorrect' (7.64% of overall trials). In total, this way 13.54% of all trials were re-coded.

Behavioral Data Analysis

After the descriptive data analysis, one-way ANOVAs were computed to compare the different conditions of the memory test categories, followed by pair-wise comparisons using Tukey's HSD test. The data of the source- and the two details-memory tests were examined under the premise of the association test: the data of the three memory tests were divided into trials that came from a correct association and those that came from an incorrect association and their average performance was determined. To gain insight into the impact of AC associative inference on the performance in the source- and details-memory tests, repeated measures 2 (AC vs XY) x 2 (correct vs incorrect association) ANOVAs, followed again by pair-wise comparisons using Tukey's HSD test, were performed.

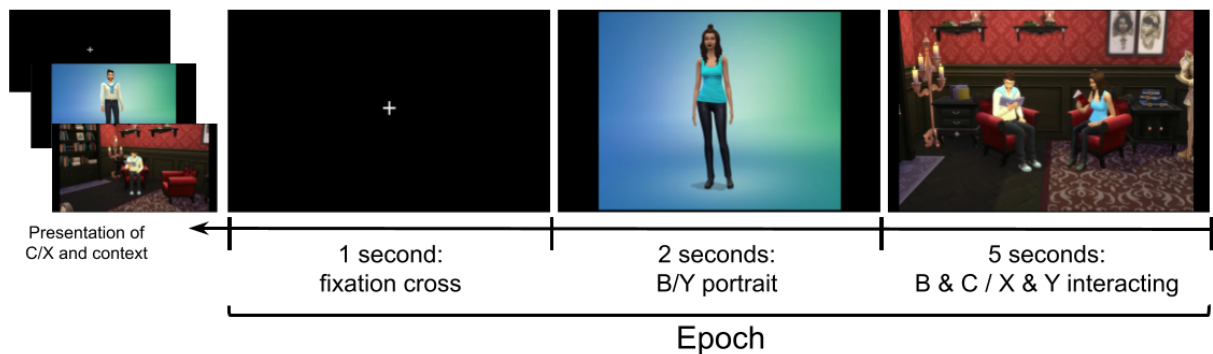
Neural Data Analysis

For the analysis of the neural data the focus was set on the encoding phase block 2, because here the BC videos were presented, potentially yielding the effect of integrative encoding when B is presented with C instead of A (see figure 2). Event-related potential (ERP) analyses and time-frequency (TF) analyses were performed on this part of the data. The epochs created during preprocessing included only the time frame of interest: the second half of BC/XY videos, meaning the part of the videos when B as a known Sim appears and then interacts with

the novel Sim C (and XY as control). These epochs covered the timings 6 s - 14 s of the whole video, starting with the fixation cross as buffer followed by the presentation of Sim B. See figure 5 for an overview of the epochs.

Figure 5

Example of an epoch.



To investigate potential integrative encoding effects, ERPs were computed. Here, the data was low-pass filtered with a cutoff of 30 Hz. A time frame of 200 ms before onset of the stimulus (before Sim B/Y would be presented) was used for baseline correction. The data were statistically handled at each node in a 2D (meaning channel x time point) grid.

The following conditions were contrasted in the analyses: First BC and XY were contrasted. However, as this can be contaminated by familiarity, a further analysis was done where BC leading to correct inference ("BCcorrect") vs BC leading to incorrect inference ("BCincorrect") was contrasted. The data was grand-averaged, and time windows of interest were visually detected. To investigate possible statistically significant differences between these conditions, cluster-based permutation tests were performed with 1000 randomizations on these time windows. This way, clusters should be found that show significant differences between the investigated conditions.

For the TF analyses, the pre-processed EEG data was then used taking the frequencies as one more dimension into consideration. The EEG data were low-pass filtered, but with a

cutoff of 50Hz. The TF representations were computed in frequency steps of 1 Hz and time steps of 0.01 s for a range of 4 - 45 Hz and, using the in FieldTrip implemented complex Morlet wavelet transform, a wavelet width of five cycles (implemented in FieldTrip). The data were statistically handled at each node in a 3D (channel x frequency x time point) grid. The same conditions as in the ERP analyses were contrasted. Again, viewing the topoplots, time ranges and frequencies of interest were analyzed exploratively and these data segments were analyzed via cluster-based permutation tests using 1000 randomizations. This way, as for the ERP analyses, the data was visually analyzed for clusters showing significant differences in brain activity between the contrasted conditions.

Neural-Behavioral Data Analysis

To investigate the relationship between the clusters found in the neural analysis and the behavioral data, correlations were computed for each of the memory-test categories. These correlations were first done for the average effect of all channels, then also for each channel for a more detailed insight. The behavioral data analysis and the neural/behavioral data analysis were both done using R (R core team, 2021).

Results

Behavioral Results

Memory performance, defined as the specificity of the four memory tests, was computed as the proportion of correct trials per subject and condition. See table 1 for a summary of the mean accuracies and standard deviations (SD) of all memory tests.

Table 1

Means and SDs of memory specificity and reaction times (RT) per memory test category and condition (N = 37)

memory-test category	condition	mean	SD	mean RT
associations	overall	.74	.44	4.80
	AB	.83	.38	4.07
	BC	.79	.41	4.35
	XY	.73	.45	4.59
	AC	.62	.48	6.21
sources	overall	.76	.43	1.64
	AB	.83	.38	1.01
	BC	.78	.42	1.03
	XY	.72	.45	1.05
	AC	.72	.45	1.51
rooms	overall	.46	.50	7.13
	XY	.46	.50	7.19
	AC	.46	.50	7.10
outfits	overall	.59	.49	3.93
	XY	.56	.50	3.96
	AC	.61	.49	3.92

For more insight into the data, one-way ANOVAs, when applicable with a Greenhouse-Geisser-correction, were performed to see if the conditions yield an impact on the means (for clarity: the df without Greenhouse-Geisser-correction would have been 1, 36). The

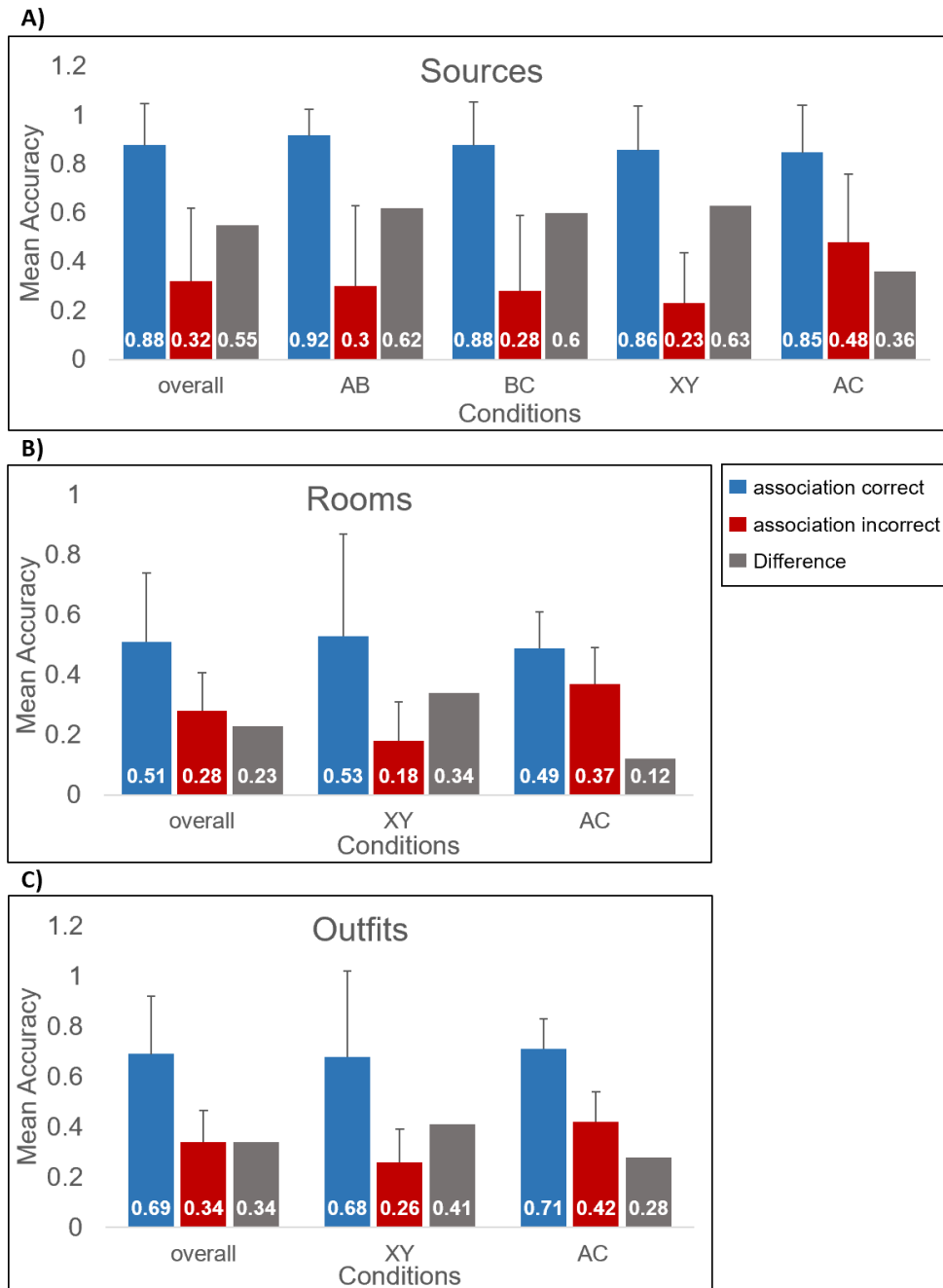
first ANOVA, testing the mean accuracies of the different conditions of the association test, was highly significant ($F(2.78, 100.13) = 42.37, p < .001, \eta^2_p = .541$). A multiple pairwise comparison using Tukey's HSD test revealed that all conditions but AB and BC ($p = .094$) differ significantly from each other (all $p < .05$), meaning that the condition of associative inference, AC, showed a significantly lower specificity rate than the other three conditions. Testing the mean RTs of the association test revealed that there is a significant difference between the conditions ($F(2.46, 88.68) = 32.68, p < .001, \eta^2_p = .476$). Here, Tukey's HSD test showed that participants take longer to respond to the AC association test requiring inference compared with the direct associations (all $p < .001$). Additionally, the response time for the direct associations is comparable, across all conditions AB, BC and XY (all $p > .05$). For the source-test, the conditions too had a significant impact ($F(2.39, 86.11) = 9.58, p < .001, \eta^2_p = .210$). Tukey's HSD test showed that AC performance was significantly lower from AB performance ($p = .003$) but not from BC ($p = .2$) and XY ($p = .999$).

So, in the association test, both the mean specificity and the mean RT of AC differ significantly from the other conditions. Participants took significantly longer and showed lower performance compared to conditions AB, BC and XY. For the source-memory test, AC does not differ significantly from conditions BC and XY, but from condition AB, showing significantly lower performance.

To test the main prediction, that the performance of source- and details-memory of trials related to correct inferential AC association would differ from when related to incorrect inferential AC association, mean accuracies of the performance for source- and details-memory tests were calculated as a function of the association test (see figure 6 and table 2).

Figure 6

Bar charts representing the mean accuracies for trials related to correct inference test trials (blue), incorrect inference test trials (red) and the difference between both (gray).



Note. The numbers in the bars are the mean accuracies per condition over all participants (N = 37). For the bars representing correct and incorrect inference related trials, the SDs are displayed. For detailed numbers see table 2.

Table 2

Memory-test performances according to correct or incorrect inference-test trials and RTs of correct inference related trials

memory test	condition	inference correct	inference incorrect	difference	mean RT inference correct
sources	overall	.877	.322	.554	1.07
	XY	.856	.225	.630	0.97
	AC	.846	.483	.363	1.40
rooms	overall	.510	.279	.231	6.90
	XY	.528	.184	.344	6.83
	AC	.492	.374	.118	6.96
outfits	overall	.688	.343	.344	3.91
	XY	.676	.264	.412	3.92
	AC	.699	.422	.277	3.90

Repeated measures ANOVAS were computed to find out if a) the condition AC (integrative encoding) and XY (no integrative encoding) and b) the performance in the previous AC associative inference and XY association test would have an impact on the performance in the memory tests for source- and details-memory. The XY condition was included in the model as a control for general memory performance. For a few of the models, missing data (due to insufficient correct or incorrect trials) led to the exclusion of up to two participants, hence degrees of freedom of < 36. For source specificity, the first repeated measures 2 (condition: XY vs AC) by 2 (correct vs incorrect association) ANOVA resulted in highly significant effects for both condition ($F(1,35) = 15.23, p = <.001, \eta^2_p = .303$) and association specificity ($F(1,35) = 166.43, p = <.001, \eta^2_p = .826$), and revealed an interaction effect ($F(1,35) = 25.16, p < .001, \eta^2_p = .418$). Tukey's HSD test revealed that for trials related to correct associations, the mean specificity of the source-memory test does not differ significantly between conditions XY and AC ($t(35) = 0.33, p = .743$), but it does for trials related to incorrect associations ($t(35) = -5.29, p <$

.001). So trials related to incorrect associations showed a higher mean specificity for source memory in condition AC than in XY. Also, AC trials related to correct associative inference showed a significantly higher performance than those related to incorrect associative inference and this too applied to the control condition XY (AC: $t(35) = -8.18, p < .001$; XY: $t(35) = -13.53, p < .001$).

For the rooms-memory test, the 2 (condition: XY vs AC) by 2 (correct vs incorrect association) ANOVA again resulted in three significant effects: condition ($F(1,34) = 11.22, p = .002, \eta^2_p = .248$), association specificity ($F(1,34) = 57.95, p < .001, \eta^2_p = .644$) and an interaction ($F(1,34) = 28.09, p < .001, \eta^2_p = .425$). Tukey's HSD test revealed that for correct association related trials, there is no significant difference between AC and XY in the mean specificity of the rooms-memory test ($t(34) = -1.46, p = .154$), but for trials related to incorrect associations, there is ($t(34) = 5.02, p < .001$). So, again, trials related to incorrect associations showed a higher performance in the rooms-memory test for condition AC than for XY. The test also revealed that participants did not perform significantly different at trials related to correct AC associative inferences compared to those related to incorrect AC associative inferences ($t(34) = 2.62, p = .061$), while for the control condition XY this comparison showed that correct association related trials lead to a significantly better performance than incorrect association related trials ($t(34) = 8.64, p < .001$).

For the outfits-memory test, the 2 (condition: XY vs. AC) by 2 (correct vs incorrect association) ANOVA revealed highly significant main effects for both condition ($F(1,35) = 21.02, p < .001, \eta^2_p = .375$) and association specificity ($F(1,35) = 91.25, p < .001, \eta^2_p = .723$) and also an interaction effect ($F(1,35) = 12.88, p = .001, \eta^2_p = .269$). The Tukey's HSD test revealed, as for the rooms-memory test, that correct association related trials did not differ in condition ($t(35) = 0.93, p = .361$), but incorrect association related trials did with AC again showing higher performance ($t(35) = 5.53, p < .001$). Then, AC trials related to correct associative inference showed a significantly higher performance than those related to incorrect associative inference

($t(35) = -6.36, p < .001$) and this too applied to the control condition XY ($t(35) = -10.56, p < .001$).

Overall, for trials related to correct associations there was no significant difference between AC and XY in any of the three memory test categories (source, outfits and rooms). The main result of interest is that for trials related to incorrect associative inferences, AC trials showed higher performance in the source- and the two details-memory tests compared to those related to correct associations.

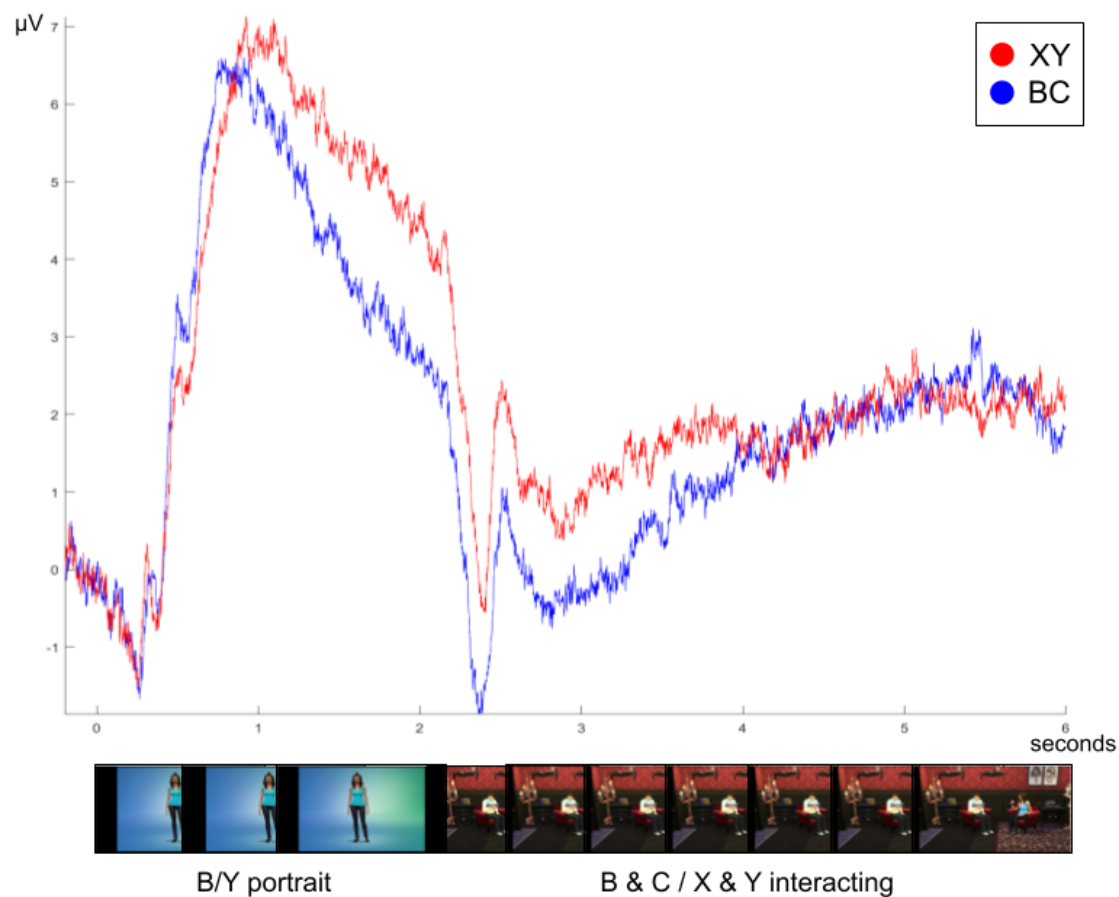
Neural Results

Event-Related Potentials

First, XY vs. BC was tested. The XY videos were used as a control because for this condition no reactivation of a related memory can happen. For BC a reactivation of the overlapping memory, corresponding to the AB-video is expected to be observed (as illustrated in fig. 2). Thus, the contrast between these two conditions reveals the reactivation of the previous overlapping memories and can consequently provide an insight about integrative encoding. The ERPs obtained in these two conditions at a representative channel are shown in figure 7.

Figure 7

Singleplot averaging channel Cz from the comparison XY vs BC

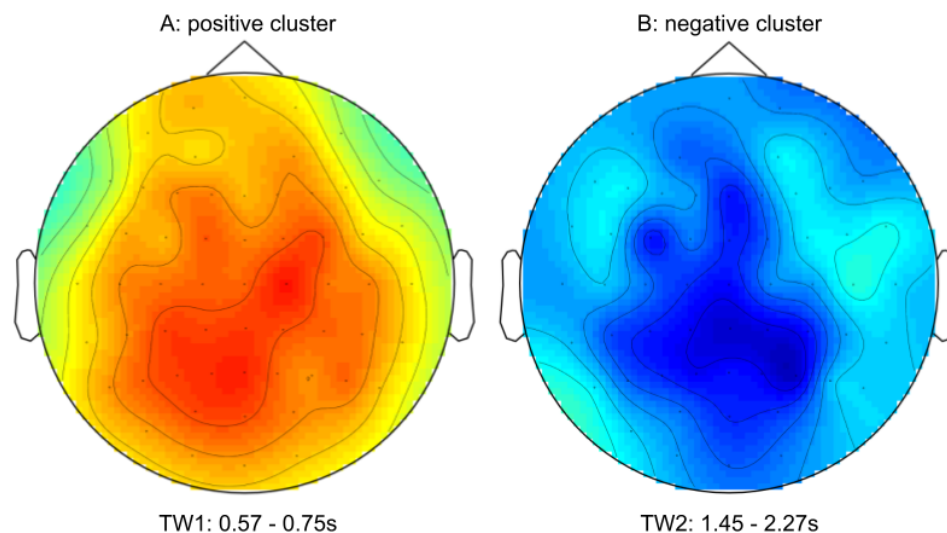


Note. The plot shows a singleplot of channel Cz of the comparison XY vs BC. Below the X-axes, the part of the videos related to this plot is displayed for reference.

Figure 7 shows potential two main effects. A positive effect (between 0.5s and 1s), followed by a negative one (1s - 4s). The statistical difference between the two conditions in these two different time windows were then examined using a cluster-based permutation test. Two significant clusters were found (Fig 8) that correspond well to what can be seen in the plot of figure 7: the first cluster is positive (where BC is more positive than XY in figure 7, 0.57s - 0.75s) and the second is negative (where XY is more positive than BC, 1.45s - 2.27s). Both effects were widespread and with a centro-posterior topography.

Figure 8

Clusters found in the ERP-analysis for BC vs. XY.



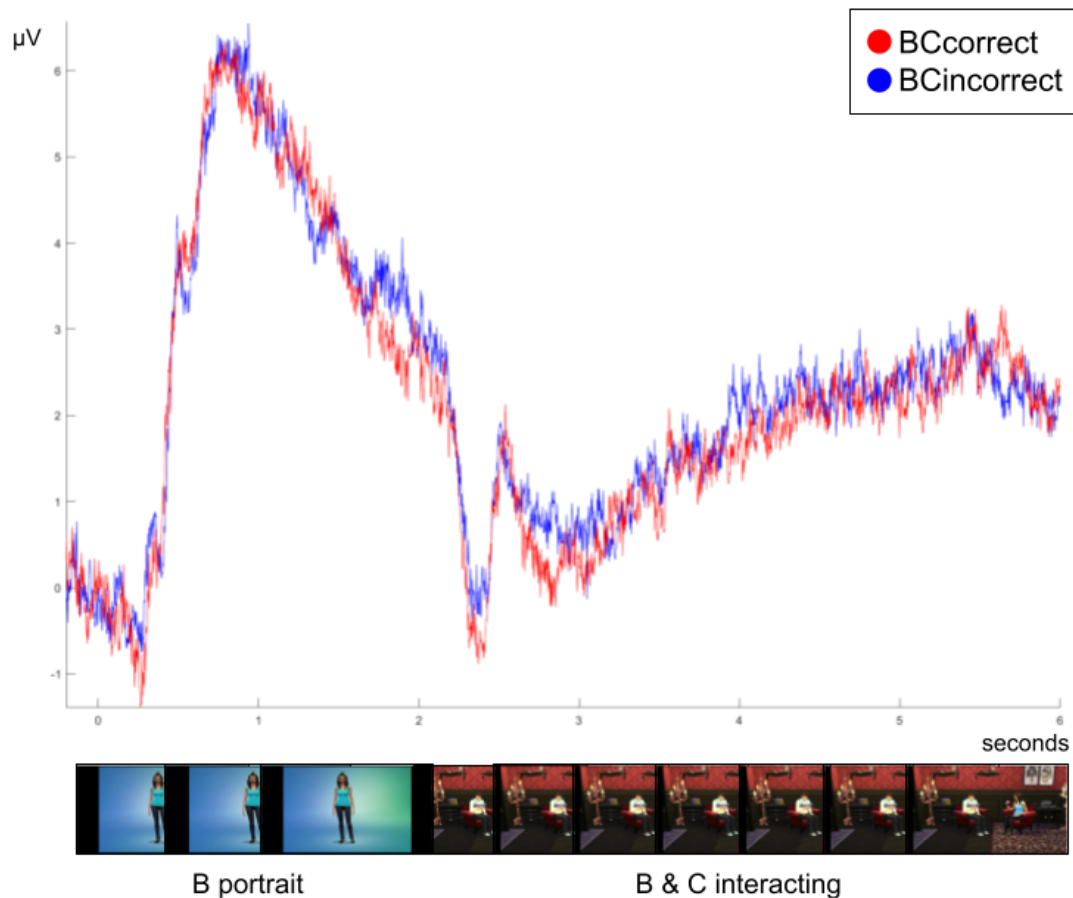
Note. The first cluster (A), ranging from 0.57s to 0.75s in the epoch, shows a positive cluster. The effect stretches widely across the channels. The second cluster (B) is a negative cluster ranging from 1.45s to 2.27s and too reaches across all EEG channels.

Considering the onset of the image-presentation of Sim B/Y in figure 7, the first effect (fig. 8A) looks similar to a N400-effect, an EEG pattern 300-500ms after stimulus onset, typical for novelty-experience or experiences of “unfit” and meaning processing (Kutas & Federmeier, 2011). This seems consistent with the expected response when B is shown together with C instead of A. On the other hand, as the videos are repeated five times and the effects seen are averages of those five repetitions, a ‘novelty effect’ could likely vanish. This and that the results of the XY vs BC comparison could be contaminated by familiarity effects as B is a known Sim while Y is a novel Sim, were reasons for the decision to test for BC related to later correct AC-inference (BCcorrect) vs BC related to later incorrect AC-inference (subsequent inference effect, BCincorrect). This contrast was done in a subsample of participants ($n = 29$) that had sufficient trials in both conditions (> 10 trials). It was expected that if integrative encoding can be

detected this way, a difference should become visible in this analysis. However, this comparison yielded no significant ERPs. See figure 9 for the ERPs plotted at a representative channel.

Figure 9

Singleplot averaging channel Cz from the correlate of potential integrative encoding: BCcorrect and BCincorrect



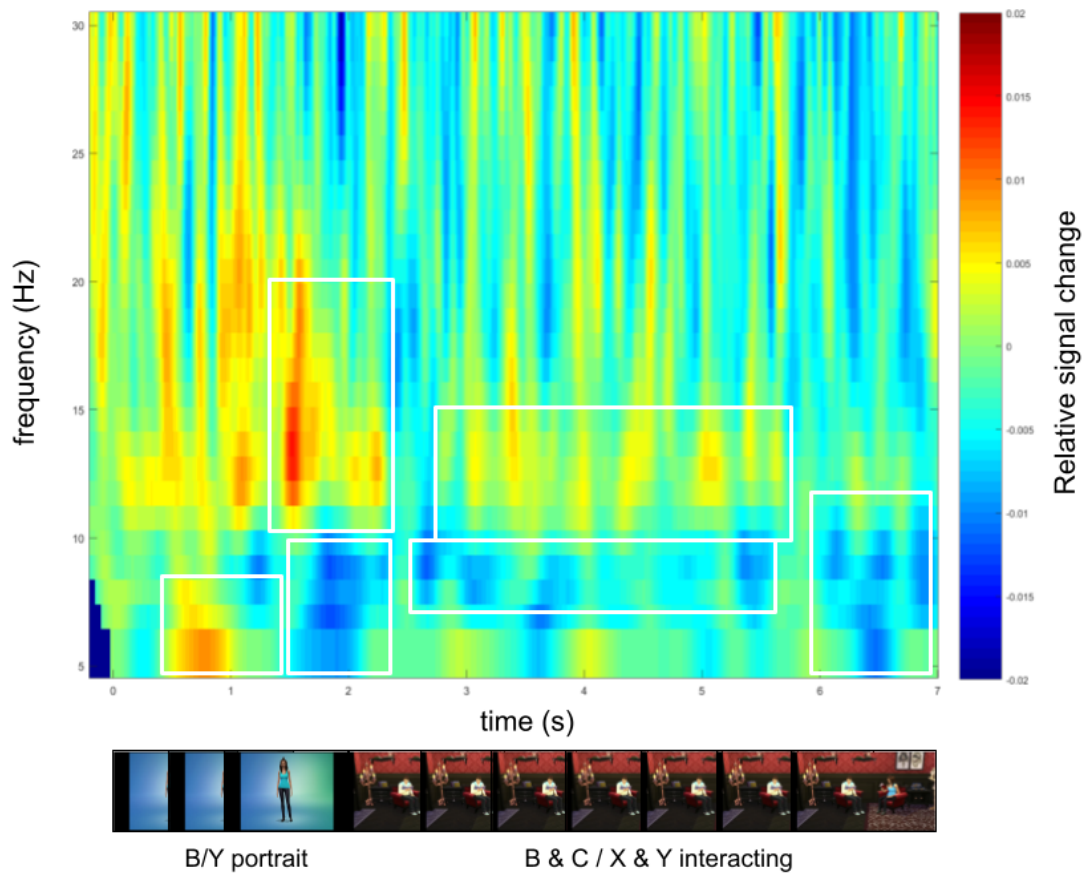
It was decided that a time frequency analysis would be more appropriate with this type of data, as of the very long epochs of 7 seconds. The reactivation of the AB episode can occur at different timings for different participants and trials. Therefore, a method like TF analysis, including the additional dimension of frequency and allowing to capture induced activity, could yield better insights into this data.

Time-Frequency Analysis

TFRs were first obtained for BC vs XY. To visually identify time- and frequency windows of interest, the TFR difference between BC and XY were averaged across all channels (see figure 10). Then, cluster-based permutation tests were carried out on times and frequencies of interest visually identified. However, no significant effects were observed.

Figure 10

Time-Frequency representation of BC vs XY for all channels with time- and frequency windows of interest tested for significance, framed in white.



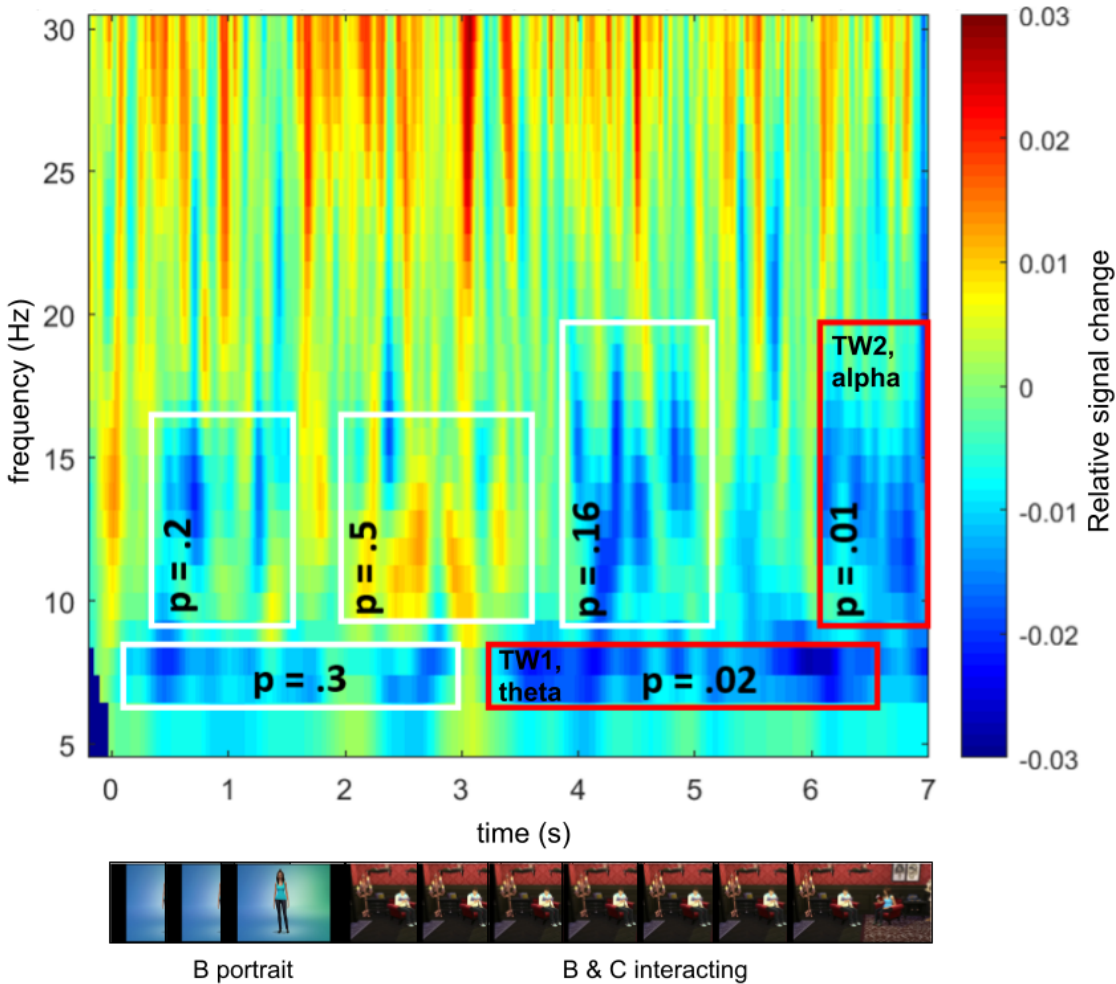
Note. The time- and frequency windows were decided upon by visual inspection of the plot. None led to significant clusters.

As BC vs XY did not yield any significant insights, BCcorrect vs BCincorrect was investigated.

Figure 11 shows the topoplot created for BCcorrect vs BCincorrect, with the time windows and frequencies of interest framed.

Figure 11

Time-Frequency representation of BCcorrect vs BCincorrect for all channels with time- and frequency windows of interest tested for significance framed with corresponding p-values.

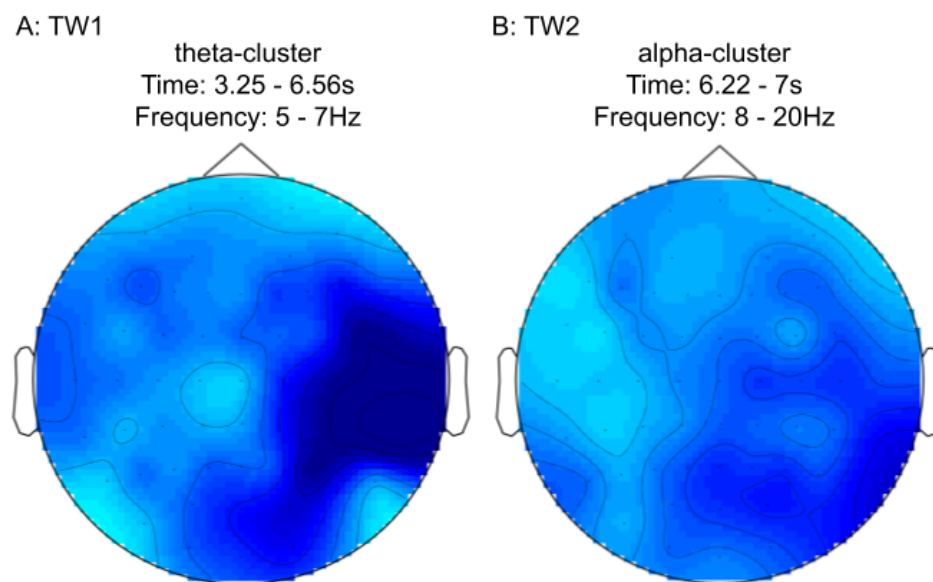


Note. The time- and frequency windows were decided upon by visual inspection of the plot. The white framed windows did not lead to significant clusters, the two red windows did yield significance (TW1, theta: $p = .01$, TW2, alpha: $p = .02$).

All times and frequencies of interest were tested and two (framed red) yielded significant clusters a theta cluster (3.23 - 6.56 s, 5-6.96 Hz, $p = .02$) and an alpha cluster (6.22-7 s, 8-20 Hz, $p = .01$). As can be seen in figure 12, both effects are negative and have a right temporal posterior maximum.

Figure 12

Clusters found in the TF analysis for BCcorrect vs BCincorrect.



In summary, here we describe two different correlates associated with the subsequent inference effect, potentially driven by integrative encoding mechanisms. One theta cluster and one alpha cluster, both during the BC interaction in the epoch.

Neural-Behavioral Data Analysis

To test the relationship between the EEG and the behavioral memory test data, the significant clusters a) averaged over all channels, and b) for each channel were correlated with the subsequent inference effects of the behavioral data. As in the ERP comparison of XY and BC TW1 showed an N400-like effect and as this could be explained as such that to recognize that the appearance of Sim B is unexpected (hence the N400 effect), the corresponding video

AB *must* have been retrieved, which could be a clue to AC interference. Therefore, this one time window was correlated with the behavioral data. However, for a) with condition AC of the association test and the mean clustered effect of TW1, no significant correlation was found ($r(35) = 0.202, p = .841$). For b), the correlations for the behavioral data with the effects of each channel, no channel showed a significant effect. Thus, a correlation with the source- and details-memory tests data was not necessary. Since for the ERP comparisons BC leading to correct vs leading to incorrect associations did not yield any significant clusters, these data were not correlated with the behavioral data.

The effects of the TF analysis were too correlated with the behavioral data in order to understand whether the neural effect found between BC videos that would later be related with correct associative inferences and those related to later incorrect associative inferences would have a relationship to the AC trials. Here, as they are related to the difference in BC-videos that would lead to correct AC-associative inferences and incorrect AC-associative inferences, they were correlated with the difference between mean accuracies of trials from the source- and detail-memory tests related to correct and incorrect AC association trials (as seen averaged in table 2). Again, they were all correlated with a) the effect averaged over all channels and then b) with each channel separately. Here for a) with sources, neither the theta cluster ($r(27) = -0.20, p = .309$), nor the alpha cluster ($r(27) = 0.04, p = .836$) showed any significance. Regarding the rooms-memory test, again a) none of the two clusters showed any significance with the averaged effect of all channels (theta: $r(27) = 0.28, p = .148$; alpha: $r(27) = 0.16, p = .411$). For b), the correlations with each channel, none of them were significant except for C6 ($r(27) = -0.42, p = .024$) and FT8 ($r(27) = 0.40, p = .032$) in the theta cluster and C6 ($r(27) = 0.41, p = .030$) in the alpha cluster. The correlations of the outfits-memory test showed for a) no significant results (theta: $r(27) = -0.19, p = 0.320$; alpha: $r(27) = -0.13, p = .503$) and for b) no channel showed significant correlations with either of the clusters.

To summarize, the behavioral data did not correlate with the EEG data measured during

the encoding phase. This means that the effects found in the behavioral for the impact of AC did not emerge during encoding.

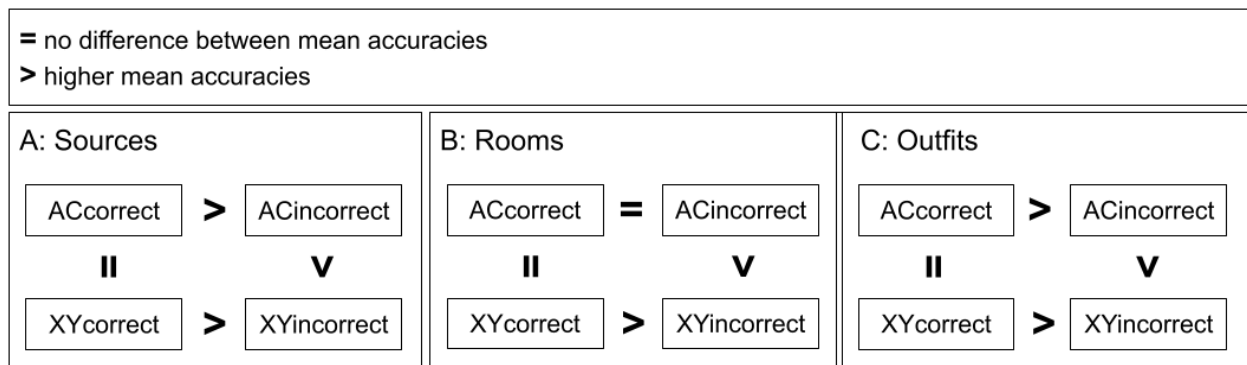
Discussion

The question driving this investigation is whether integrative encoding mechanisms, associated with generalization across overlapping events, comes at the cost of memory specificity for the events. I designed a task that required participants to make inferences across overlapping events. In order to trigger integrative encoding, I used narrative videos that were repeated several times (Zeithamova et al., 2016). If there is a relationship between memory generalization and specificity I expected that memory specificity, measured by source- and details-memory of the individual events, would differ between events leading to correct AC inference and events leading to incorrect AC inference (Hypothesis 1). Additionally, I expected the neural subtract of integrative encoding, measured with EEG during encoding, to be predictive of source- and details-memory performance (Hypothesis 2).

The behavioral data can be declared as supporting Hypothesis 1. Figure 13 schematically summarizes the conclusions of this investigation.

Figure 13

Schematic overview of the conclusions resulting from the analysis of source- and details-memory tests



Note. the schema summarizes the relationships between the different conditions as a function of association specificity: trials related to correct inferential AC association (ACcorrect), related to incorrect

inferential AC association (AC_{incorrect}), related to correct XY association (XY_{correct}) and related to incorrect XY association (XY_{incorrect}), for each the sources memory test (A), the rooms memory test (B) and the outfits memory test (C) is displayed.

As can be seen in figure 13, the specificity was higher for correct association related trials than for incorrect association related trials and this was the case for both AC and the XY control condition. Overall, no costs of inferential memory associations, hence of memory generalization and integrative encoding, on memory specificity could be found. On the contrary, inferential memory associations were associated with higher memory specificity, indicating that events for which participants have a higher memory specificity are those events that will also lead to more correct inferences. Sanchez and Zeithamova (2020) used a different paradigm, but also did not find any sign of costs of memory generalization in the form of a loss of source memory. As their paradigm differs from an AIP, the results should be compared only carefully. Carpenter and Schacter (2017) did use a comparable paradigm to the one of this study, an AIP, but they did find poorer performance on details-memory-tests for trials following successful inference compared to those following unsuccessful inference. They too presented the stimuli in contexts, but not in videos like it was done in this project. Carpenter et al. (2021) found similar results in a follow-up study. The work of Banino et al. (2016) summarizes four studies, all finding source memory loss as a consequence of memory generalization in an AIP paradigm. The differences between memory performance of conditions XY and AC related to unsuccessful association can be interpreted as such that participants could have preserved, separate memories for A and C, hence the better performance in the source- and details-memory tests, but could not link the A with the C.

Hypothesis 2 and its sub-assumptions (H2.1-2.4) were not entirely substantiated by this study. The neural data showed two different neural correlates potentially associated with integrative encoding mechanisms. The TFR analysis showed that BC-trials leading to correct

inferential AC association were associated with more theta and alpha desynchronization.

Successful encoding is associated with theta synchronization and alpha desynchronization (Hanslmayr et al., 2012). So while the alpha desynchronisation is found in the EEG data of this study, the theta desynchronization is unusual and unexpected. According to Staudigl et al. (2010) theta band amplitude decreases predict successful inference resolution. However, these effects were not predictive of the source and details-memory. Thus, both the neural and the behavioral data show no evidence that memory generalization, associated with integrative encoding mechanisms, result in a decay of memory specificity. This leads to the assumption that both integrative encoding (as found as two effects in the EEG data) and flexible retrieval (as the behavioral data suggests separate representations of A and C) may play a role in memory integration.

Limitations

There are some aspects of this work that might have an impact on the results. Regarding the test material, the benefit of vivid, narrative-like videos lead to an experiment with potentially higher ecological validity than the classical AITs. But the stimuli prepared with a video game come with downsides, too. While other studies used photographs of objects and/or pictures (Carpenter & Schacter, 2017), the stimuli in this study were created using a life-simulation computer game. The stimuli in this study were to a certain point limited in their presentation. Although there were many possibilities for the most realistic design possible and this may be an advantage in comparison to other studies, the ideal of absolutely natural stimuli cannot be achieved. There is only a limited amount of furniture, colors, clothing and also in the design of the faces in the game. Especially children or seniors could be individualized only with difficulty clearly from each other. Furthermore, the Sims are always the same size per age category. There is less variation and differences between stimuli than between real people. Very similar faces of some of the Sims not related at all could have caused irritation for the participants and noise in the data. And even though this study design aims to be more naturalistic than previous

designs, it still presents only visual stimuli. More layers of context, as names for the Sims or audio presenting conversations would have potential to create an even more life-like experiment. Of course, the more realistic an experiment, the more difficult it will be to operationalize and analyze.

There are some practical issues related to this study. One is that the videos were repeated several times. This was done to trigger an integrative encoding mechanism (Zeithamova et al., 2016) and also to assure qualitative EEG data. This way, the paradigm got less naturalistic, as in the real world one would never encounter the exact same situation five times before being confronted with an overlapping experience, again for five times. This is a trade-off that comes with obtaining neural data using EEG. Another issue caused by practicality is that the memory tests were done directly after the encoding phase had ended. Participants could take a break, but it mostly took no longer than five minutes. This too is not very life-like, as usually after the first event time spans of several days, weeks or even months can occur before one encounters a situation qualifying for memory integration.

The rooms-memory test was not as well thought through as it could have and this was only becoming present during data analysis. The original idea had been to weigh the four different possible options as the three wrong options are not equally incorrect. However, due to the re-coding of "guesses" and trials with RTs > 10, the rooms-data got distorted. Therefore, the results of this section of the study should be considered with caution, as I decided to just count the correct rooms as the correct answer and all other options as equally wrong, which does not reflect the reality of the stimulus material.

Implications and future research

This study found no evidence that integrative encoding mechanisms have an impact in memory specificity - despite many previous studies finding a cost of memory integration in the form of memory loss - associative inferences did not lead to lower memory performance in source- and details-memory tests. It is important to recognize, however, that all of these

previous studies used the classic AITs in which objects or people with objects were presented as pictures in no or quite unnatural contexts. The design of this study is very different from that. The stimuli, in this case human-like figures instead of objects, were shown in a quite natural context and they interacted with each other. On several levels, a more natural stimulus material was thus made possible. It could be that the natural context, the everyday-looking situations, and the narratives, rather than making the paradigm more challenging, served as further cues to the brain. This seems obvious in that the brain evolved in a very complex world and thrives accordingly, rather than paying with source- and detail-loss for a basic cognitive function such as generalization.

Regarding the discourse, if integrative encoding or flexible retrieval is the process driving memory integration, this study focuses on integrative encoding. However, flexible retrieval mechanisms may also be involved in memory generalization and AC inference associations.

As such, follow-up analysis should investigate the EEG data collected during the retrieval phase and correlated with the behavioral data of the source- and details-memory tests. Also, more sophisticated analyses for the EEG data like representational similarity analysis or multivariate pattern analysis could be computed for better insights. Implementing a longer time period between the encoding and the retrieval phase could be considered for future research. The temporal component plays an important role in whether integrative encoding or flexible retrieval (or both) are important for memory integration. To date, there are few studies that have taken advantage of the high temporal resolution of the EEG in this question. Many of the studies that have provided promising insight purely with behavioral data or with fMRI data should also be done with EEG in this way or in an optimized way.

The results of this study open up intriguing questions: not finding any loss of memory as a consequence of associative inferences and producing results that even assume the contrary - stronger memory even for failed associative inferences compared to simple associations, brings up the question whether the way memory is studied can do justice to the complexity of the

environment and the mechanisms involved. More studies using paradigms as life-like as possible should be done to form a more stable study base. If other studies this way could replicate the findings using more classical AIT approaches, this tells that the research can be performed in a more economic way compared to more realistic settings. But if these studies also contradict with earlier findings, the course of memory research should be reflected on and possibly adjusted.

Conclusion

This study brought up results that do not reproduce most of the publications related to memory integration. It can be understood as evidence that both integrative encoding and flexible retrieval played a role in memory integration in this paradigm. With the two neural effects found during encoding, evidence for integrative encoding has been recorded. That this did not occur at the expense of memory specificity and is not related with retrieval, suggests that subjects held memories of Sims A, B, and C separate and retrieved the information when generalization was needed during the memory tests. Thus, EEG data from the retrieval phase of this experiment should be investigated. This adds exciting insights to the existing body of research and contributes not only to the integrative encoding / flexible retrieval debate, but also to the investigation of possible costs of memory integration in the form of memory loss. It raises interesting questions that should be explored in future work.

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Appendix A

Participant Informed Consent Form

Information for participants

General Information about EEG

Information processing in the central nervous system occurs by electrical activity of the nerve cells. This electrical activity is possible to measure by using electrodes attached to the head. Such measurement is called an Electro-Encephalo-Gram, or EEG for short. An EEG apparatus measures and records small differences in electrical activity produced by the brain.

Preparation at home

1. Do not use gel, hairspray, etc.
2. Do not use face cream.
3. Bring your eyeglasses, also if you normally use contact lenses
4. Do not drink alcohol or consume other drugs the night before the experiment
5. If you feel that you are too tired to participate, please contact the responsible researcher and book another time (ki1473fr-s@student.lu.se)
6. Please try to layer your clothing so that you can control your own body temperature in case the lab space is too warm or too cold for you.

Preparation at the Lab

The preparation of the EEG experiment typically takes around 30/40 minutes. You will get instructed about what you have to do during the experiment and sign a form of informed consent. A cap (sort of bathing cap) will be tied on to your head. On this cap there are measuring electrodes. To obtain good signals it is important that the resistance of the skin is not too high. In order to do that the experimenter will make sure the skin resistance drops to the desired value by gently cleaning the area under the electrode with a small amount of alcohol or conducting gel. This procedure is totally safe and is not painful. However, it will take some time. If you want, and to make the most out of your time, you can bring a book to read or your study material.

Once the cap fits and sits well, we will ask you to get up and let us create a 3d-model of your head with the cap using a special camera device. This is important for data processing later. The model will be handled with utmost respect for your privacy, not shared anywhere and deleted as soon as not needed anymore for the research project. The model will not look much like you.

The experiment

After the preparation you will be placed in the experiment room. You will be reminded about what you have to do during the experiment. During the measurement the door of the experiment room will be shut but not locked, and the experiment leader can see you through window. You will not notice anything from the measurement. When the experiment is completed, the experimenter will bring you out of the experiment room and remove the cap with electrodes. The gel stuck to your hair can be removed easily with water. If you want you can rinse out your hair and dry it with a towel (we have a shower at your disposal, but if you want you can bring a hat and wash off at home). The experiment is completely safe and painless and does not require any injections or the intake of any substances.

Background and purpose of the experiment

The general purpose of the study is to increase understanding of basic episodic memory functions and to investigate how memories are organized in the brain. After the experiment is concluded more specific information can be given to you.

The experiment consists of two phases. In the first phase, you will watch videos of two Sims (characters of the computer game The Sims 4) interacting with each other. In this phase, we want you to try to learn who is linked with whom. In the second phase, your memory performance for the learned material is going to be measured. The experiment takes about 180 minutes, including the application of the electrodes.

Compensation for Participation

Every participant will get a compensation in form of a voucher worth 200 SEK after participation.

Management of the data

Personal data from the study (which include computerized behavioral tests and EEG measures) will be stored in an anonymizing format. Your data is confidential, and no unauthorized person has access to it. When the data from the study will be published the individuals will not be identified.

If you have any other questions about the study and the procedure, please contact:

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INFORMED CONSENT

I am satisfied with the information about the experiment and have read the written information well. I have had the opportunity to ask questions about the experiment, and I am satisfied with the answers. I have carefully considered my participation in the experiment, and I understand that I have the right to withdraw my participation at any moment with or without reason to do so.

I give my consent to take part in this experiment:

Full name (readable):

Date of birth:

Signature: **Date:**.....

To be filled by the researcher

The undersigned declared that the participant named above has been informed both in writing and in person about the experiment. The participant is informed that the experiment will be immediately stopped if requested, and that this will not affect the care that s(he) deserves.

Date:

Name:

Signature: