Mnemonic Influence:
How Memory Impacts Emotion, Reason, and Action

by
Madalina Vlasceanu

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Contents

1. Introduction

a. The appeal to manipulate memory

People have been intrigued by the idea of manipulating memory since well before this era. One of the earliest dating evidence in history of attempts to improve one's memory, points to a Greek poet, Simonides of Ceos, who lived in the 4th century BCE. Simonides is credited with the invention of the memory palace technique, by Cicero in his book written in 55 BCE (Yates, 1966), where he describes the story of Simonides attending a banquet to deliver an ode to a Thessalian nobleman. As Simonides leaves the hall, the roof collapses on everyone attending the event, leaving no survivors. With no records to identify who was in the room or where in the room the attendees were sitting, the families of the victims are desperately searching through the collapsed building for familiar objects to identify their loved ones. Simonides, then, thinks back of the moments right before the collapse, recalls where everyone in the room was sitting, and guides the families to the exact locations of their relatives. With this legend, the *art of memory* was first documented (Foer, 2011).

We now conceptualize the memory palace as a mnemonic device that enhances memory by improving information retention and retrieval, heavily relied upon by not only ancient Roman and Greek civilizations, but also by current contestants of memory championships. This technique works by first requiring those trying to memorize a list of items to imagine walking through a familiar environment, such as one's house or palace, and placing the items they want to memorize along the path. Then, to recall the items, they have to simply re-imagine walking through the same path, seeking the items as they go.

But as old as the desire to improve one's memory is also the desire to selectively delete one's memories. According to Cicero, right after the invention of the memory palace method, people started expressing their need for a forgetting method: "I would rather a technique of forgetting, for I remember what I would rather not remember and cannot forget what I would rather forget" in the words of Themistocles (cited in Campbell, 1991).

Fast forwarding from ancient to modern times, the desire to control what to remember and what to forget is still a reality. For instance, aggravated by memory retrieval failures, some people express the aspiration to have a perfect memory. One such example is Joshua Foer, a freelance journalist and author of the international bestseller *Moonwalking with Einstein*. In his book published in 2011, Foer confesses his belief that if he was able to remember everything, he would be not only smarter, but a better journalist and friend; he then describes his journey of training to improve his memorizing skills using the memory palace method, which led him to compete in memory championships and even win one.

A common theme across these examples is the desire to control memory in order to increase projected wellbeing. But would being able to do so actually help? An even more pressing question is, are people able to manipulate memory? If so, with what implications for other mental processes closely interlinked with memory, such as emotions, beliefs, or decisions? The current consensus in the field of memory research is that memories are malleable in numerous ways, a phenomenon enabled by the mechanisms that underpin this cognitive process. In this review, we propose the term for referring to the use of these mechanisms to be *mnemonic influence*: the conscious or unconscious, endogenous or exogenous, usage of a memory

mechanism by an agent, to deliberately or incidentally manipulate the memory of a target, including the self.

This article first describes the features of memory that enable its malleable nature, and then dives into the impact memory manipulation could have on other interdependent mental processes such as emotions, beliefs, and decisions. The investigation of the connection between memory and other mental processes is a fairly new research trajectory, so much of this topic is yet to be discovered, though new research has started uncovering some interesting pieces of this puzzle. Finally, this article concludes by addressing ethical implications of memory manipulation.

b. Memory is malleable

Historically, people conceptualized memory as *the tape recorder* of our experiences, ascribing memory a mechanical accuracy. Even though psychologists such as William James (1890) and Frederic Bartlett (1932) insinuated human memory is reconstructive and subject to change, as late as 1980, most scientists studying memory still believed in the *tape recorder* interpretation of the memory system. "Everything we learn is permanently stored in the mind although sometimes particular details are not accessible" was a statement most researchers used to agree with in 1980 (Loftus & Loftus, 1980). As evidence in favor of this view, scientists were citing Wilder Penfield's experiments conducted between 1934 and 1954. The Canadian neurosurgeon used electrical probes to stimulate the brains of conscious epileptic patients. Penfield's patients described experiencing recall of vivid memories as the temporal lobes were electrically stimulated, thus concluding that the brain contains a complete record of past experiences (i.e., the memory-permanence hypothesis). Most scholars today agree that Penfield's temporal lobe stimulation elicited hallucinations, and not real memories.

Others questioned the "videorecorder model", suggesting through a series of experiments that original representations can be replaced, erased, and distorted (Loftus, 1975, 1977, 1979). This evidence led the field to question the arguments previously used in support of the memory permanence theory (e.g., hypnosis, electrical stimulation) (Loftus & Loftus, 1980). For instance, it was proposed that what had previously been interpreted as memory recoveries, could have actually been reconstructions of past experiences that were actually different from the original experiences. First, it was argued that Penfield's brain stimulation did nothing more than induce dream-like synthetic constructions, a view initially held by Neisser in 1967, who argued that Penfield's work "tells us nothing new about memory" (Neisser, 1967). Second, a similar critique was put forward against the belief that hypnosis is successful in recovering memories, proposing that most of the recollections experienced by subjects during hypnosis are fabricated (Loftus & Loftus, 1980; Neisser, 1967).

We now know that memory is undoubtedly malleable in many ways, notably emphasized in Daniel Schacter's 2001 book *Seven Sins of Memory*. Schacter groups the seven memory *sins* into two categories: sins of omission (transience, absent-mindedness, blocking) and sins of commission (misattribution, suggestibility, bias, persistence). Schacter concludes his book arguing that these apparent *sins* are actually adaptive features of the memory system (Schacter, 2001).

Moreover, we now also know that not only memories are malleable, and subjected to external influences, but more surprisingly, that even the brain structures associated with memory processes have been suggested to structurally adapt to environmental demands. The locus of

memory at the biological level is the brain structure known as the hippocampus. The hippocampus plays important roles in the consolidation of information from short-term memory to long-term memory, and in spatial memory that enables navigation (Andersen et al, 2007). The idea that the adult human hippocampus can change its structure in response to environmental demands was recently tested by scanning the brains of London cab drivers. This research found that the right posterior hippocampus, area involved in spatial navigation, was 7% larger in London cab drivers compared to matched control subjects. Also, the volume of this brain structure correlated with years working as a taxi driver, suggesting the hippocampus can expand to accommodate people dependent on navigational skills (Maguire et al, 2000).

So, the scientific community is now aware of the manifestations of the malleability of memory at both the behavioral and neural levels. But what are the cognitive mechanisms that underpin these manifestations?

2. Mechanisms that enable malleability

The mechanisms that lead to memory's dynamic nature can be grouped into acquisition and forgetting processes (Squire, 1986), both explored in detail in this section. As part of the acquisition processes, consolidation and reconsolidation are explored here, and to illustrate the forgetting processes this section describes mechanisms such as decay, interference, retrieval induced forgetting, as well as intentional forgetting mechanisms.

a. Acquisition

Consolidation and Reconsolidation

Consolidation and reconsolidation are construed from evidence of an instability period that memories undergo. In the case of consolidation, this transient phase is initiated after the acquisition of new information, and in the case of reconsolidation, after the reactivation of an existing, previously consolidated memory (Nader & Hardt, 2009). During an instability period, the respective memories become malleable, and subject to influence (Fig. A1).

Consolidation is the time dependent process by which a memory becomes firmly established and interconnected (Muller and Pilzecker, 1900; review by McGaugh, 2000). This process occurs both at the synaptic level, described as structural changes in the connections between neurons as a new memory gets formed (Dudai, 2004), and at the systemic level, as the hippocampus initially involved in encoding the new memory, transfers the memory to the cortex (information in short term memory is transitioned to long term memory) (Squire 1992).

Significant advances in the consolidation literature were achieved by the study of HM (Henry Molaison), a patient with most of the medial temporal lobe (MTL) removed to relieve his epilepsy (Scoville & Milner, 1957). After the surgery, HM became incapable of forming new episodic memories and remembering events that occurred before the surgery. However, despite the dramatic memory impairment, HM's intellectual ability was unaffected. Moreover, he was able to acquire and access new motor skills, which contributed to the discovery that the hippocampus is involved in explicit (episodic) but not implicit (procedural) memory processing (Milner, 1966).

Further empirical evidence for the consolidation process was documented in studies showing the impairment in performance on recall tasks using electroconvulsive shock (Duncan, 1949), protein synthesis inhibitors (Flexner, Flexner, Stellar, 1965), or new learning (Gordon &

Spear, 1973), when administered right after learning, suggesting that memories become more stable and thus consolidated, in time (Nader & Hardt, 2009). Therefore, memories are flexible and subject to distortion at the phase of initial encoding before consolidation occurs.

Memory is also subject to manipulation during reconsolidation (Fig. A1). Reconsolidation refers to the process by which memories are altered by retrieval (Nader, Schafe, and LeDoux, 2000). Each time a memory is retrieved, it is not simply being passively read, it is reconstructed, becoming vulnerable to distortion, and it has to be restabilized through reconsolidation. The term reconsolidation was introduced by Spear in 1973, after Schneider and Sherman (1968) and Misanin, Miller, and Lewis (1968) found that procedures used to induce amnesia impaired consolidated memories only if these were reactivated prior to the treatment. However, the idea behind reconsolidation had been illustrated arguably long before the term was coined, even though conceptualized differently: William James (1890), in his book *Principles of Psychology* suggested that retrieval of a memory in a different context can change the nature of that memory. Bartlett (1932) tested this idea experimentally, by asking participants to read stories from different cultures, and later asking them to recall the stories. Bartlett found that people's recollections of the original stories were not perfect, instead they were interpretations of the original stories imbued with the participants' own cultural knowledge. This result first supported the reconstructive nature of human memory (Bartlett, 1932).

Work on reconsolidation has been conducted on many species, from roundworms (Rose & Rankin, 2006) to humans (Schiller & Phelps, 2011), with the most notable mass of work documented in rodents (Nader and Hardt, 2009). A classic rodent study that brought reconsolidation, the way it is currently referred to, onto the scientific scene, targeted the reconsolidation process of an auditory-fear memory in rats: the rats were first conditioned to associate an auditory stimulus to a fear response; one day after conditioning, the rats were reminded of the conditioning session by ringing the tone used during conditioning; at this point, the researchers administered an intra-amygdala dose of anisomycin, an antibiotic that inhibits protein synthesis, commonly used to impair memory consolidation; this procedure led to impaired long-term memory of the auditory fear response when administered right after reactivation of the memory, but not when administered 6 hours after the reactivation (Nader, Schafe, LeDoux, 2000). This result demonstrated not only that is it possible to manipulate a previously consolidated memory, but also that the reactivation-induced instability was temporary. Following this initial demonstration of the phenomenon, hundreds of other studies documented reconsolidation across different tasks (Nader and Hardt, 2009).

In humans, reconsolidation has also been documented and disrupted as a targeted attempt to alter memories, through techniques such as: the administration of electroconvulsive therapy (Rubin, 1976), the administration of propranolol (Kindt, Soeter, Vervliet, 2009; Brunet et al, 2011), interference from new learning (Walker, Brakefield, Hobson, & Stickgold, 2003; Forcato et al., 2007; Hupbach et al., 2007), or impairment from a subsequent emotionally aversive stimulus (Strange et al, 2010).

Weakening

To investigate the potential to weaken a memory by disrupting reconsolidation, researchers have first targeted undesirable memories, attempting to reduce their accessibility. For instance, Rubin (1976) investigated the effect of electroconvulsive therapy (ECT) on human subjects suffering from symptoms of psychopathology such as obsessive memories. He found that the obsessive

memories retrieved right before an ECT session were weakened, thus alleviating the symptoms of the disorder.

Another example of memory manipulation through reconsolidation disruption in human subjects is a study conducted by Brunet and colleagues (2008) who used a drug therapy technique to reduce the distress caused by memories of traumatic events in people suffering from post-traumatic stress disorder (Brunet et al, 2008). Thus, propranolol has been successful at disrupting emotional responses (e.g., fear) and psychophysiological responses to traumatic memories (Brunet et al, 2008; Kindt et al, 2009). Human declarative memories, the class of consciously recalled memories, have also been successfully impaired, most commonly through procedures involving retrieval-relearning (Chan & LaPaglia, 2013), interference (Forcato et al, 2007) or clonazepam (Rodriguez et al, 2013).

Episodic memories, the subclass of declarative memory for personal experiences, are different from non-declarative memories in that they are thought to be hippocampus-dependent and have representations in cortical regions (for review, see Davachi, 2006), thus their manipulation could function differently. Episodic memory was successfully impaired during reconsolidation when reactivation was followed by an aversive emotional stimulus (Strange, Kroes, Fan, Dolan, 2010). This deficit in the episodic memory recall was shown to only occur 24 hours after the manipulation (consistent with the reconsolidation disruption interpretation) and to last at least one week. The proposed mechanism suggests an amygdala dependent adrenergic release evoked by the fearful stimulus enhanced the memory for the aversive stimulus at the cost of the memory that was active in the four-second window preceding the exposure to the aversive stimulus.

Updating

Memory updating through disruption of the reconsolidation of episodic memories in humans was investigated by Hupbach, Gomez, Hardt, and Nadel (2007): participants first learned a list of objects; a day later, half of the participants received a reminder of the list and then learned a second list, while the other half did not receive a reminder of the list before learning the new one; finally, a day later, memory for the first list was tested. The results revealed that participants who received the reminder of the first list before learning the second one, performed worse at the test for the first list, intermixing items from the second list in the first. A follow up experiment using the same procedure also showed that memory for the second list was not affected by the reminder, thus only the original memory was modified. The authors concluded from these results that reconsolidation is a constructive process, through which new information is incorporated in memory (Hupbach et al, 2007).

Strengthening

Rodriguez and colleagues (2013) investigated the potential to manipulate human episodic memory, this time by strengthening it, during reconsolidation, using clonazepam (benzodiazepine GABA-A agonist): participants first studied five cue-response syllable pairs; a day later, participants were shown the cue syllables to reactivate the memories for the pairs, after which they were administered the clonazepam in high or low dose, or placebo (a control group was administered the drug without the memory reactivation); a day later, participants were tested on the pairs of syllables, by being shown the cue, and being asked to provide the corresponding learned response. The results revealed an improvement in performance for the group that received the high dose of the drug after memory reactivation, compared to the low drug group,

the placebo group, and the no reactivation group. These results indicate the pharmacological potential to strengthen human episodic memories during reconsolidation.

Thus, successful memory manipulations (weakening, updating, strengthening) during retrieval, through reconsolidation disruption or alteration, have been documented in many types of memory, such as motor memory (Walker et al, 2003), spatial memory (Rossato et al, 2006), emotional memory (Schiller et al, 2010), verbal memory (Strange et al, 2010), and declarative memory (Hupbach et al, 2007), revealing one of the mechanisms that enables mnemonic influence.

b. Forgetting

i. Trace decay

Another mechanism that enables mnemonic influence is trace decay. Decay, the simplest mechanism of forgetting, is defined as the increase in forgetting (conversely, the decrease in memory) as time progresses (Fig. A2). Decay was first studied by Hermann Ebbinghaus, the psychologist who pioneered the experimental study of memory (Ebbinghaus, 1913). Using himself as the subject of his research, Ebbinghaus studied 169 lists of 13 nonsense syllables each. He then restudied each list after differing intervals, spanning from 20 minutes, to 31 days. Ebbinghaus thus mapped the forgetting curve, referring to the quantitative relationship between memory and time, as a logarithmic decline in memory with time (Ebbinghaus, 1913; replicated by Murre & Dros, 2015). One critique of Ebbinghaus's approach to studying memory decay was the lack of ecological validity of his stimuli. Meeter, Murre, and Janssen (2005) designed a more naturalistic study to address this limitation: they recruited 14,000 participants and showed them 40 news headlines each, randomly drawn out of a total of 1000 headlines of events that occurred over a 4-year period. With this method, the researchers confirmed Ebbinghaus's findings extend to ecologically valid circumstances (Meeter, Murre, Janssen, 2005).

Trace decay, the gradual weakening of memories in time, is still a topic that is currently under scientific investigation. Some scientists have proposed that even though the activation of information decays, it might still be stored (Baddeley, 1998; Gold, Murray, Sekuler, Bennett, Sekuler, 2005). Even though this is a very appealing stance, the alternative possibility, that decay occurs simply through complete erasure of the memory trace, has not yet been dismissed. In other words, whether decay means inaccessibility of a memory trace (trace is still stored but the ease of accessibility has decreased) or unavailability of a memory trace (trace is no longer stored in memory) remains unanswered (Baddeley et al, 2015).

ii. Interference

The malleability of memory is also enabled by the cognitive phenomenon known as *interference*: the presence of similar memory traces compromises retrieval (Muller and Pilzecker, 1900) (Fig. A3). In other words, interference arises when a cue becomes associated with more than one target; the more targets that are associated with that cue, the worse the recall of any of them becomes (cue overload principle; Watkins, 1979). The widely accepted mechanism of interference explains the process using the competition assumption: memories associated with the same cue automatically compete with and impede each other's retrieval in the presence of the cue (Anderson, Bjork, Bjork, 1994).

One type of interference is retroactive interference: forgetting of older memories due to the encoding of similar newer memories. The simplest example of retroactive interference is

demonstrated by the following design: participants learn a list of paired words (cue-target 1) and then a second list of pairs (cue-target 2) in which the same cues of the first list are associated with different targets; then participants are asked to recall the first targets they studied when exposed to the cues; their memory performance is compared to that of a different group who only studied the initial list, engaged in a distracter task, then recalled the targets associated with the cues. The difference in performance between the two groups describes the amount of retroactive interference experienced (Barnes & Underwood, 1959). This effect has also been shown with personal memories, as a more realistic memory context (Hitch & Baddeley, 1977).

Another type of interference is proactive interference: difficulty to retrieve newer memories due to similar older memories (Underwood, 1957). To study this memory process, the design adopted by researchers is similar to that of retroactive interference described above, with minor adaptations: participants learn a list of paired words (cue-target 1) and then a second list of pairs (cue-target 2) in which the same cues of the first list are associated with different targets; then participants are asked to recall the second targets they studied when exposed to the cues; their memory performance is compared to that of a different group who first engaged in a distracter task, then studied the second list, and then recalled the targets associated with the cues. The difference in performance between the two groups describes the amount of proactive interference experienced (Underwood, 1957).

Thus, proactive and retroactive interference are mechanisms of forgetting by which a memory can be manipulated through the insertion of competing memories either before or after the targeted memory. These mechanisms of forgetting also contribute to the malleable nature of memory, enabling mnemonic influence.

iii. Retrieval Induced Forgetting (RIF)

Moreover, he transient nature of memory is also exhibited through the phenomenon known as *retrieval induced forgetting (RIF)*: retrieving a memory hinders the accessibility of other related but unretrieved memories (Anderson et al, 1994) (Fig. A4). The selective practice paradigm, the basic paradigm used to illustrate RIF, is structured in three phases: in the first phase, participants study category exemplars (e.g., fruit – apple, fruit – orange, tree – oak, tree – pine); they are then asked to retrieve the exemplars when presented with the category and a cue (e.g., fruit – or-) – this is the retrieval practice phase, and participants are asked to practice half the exemplars from half of the categories; finally, they are tested on all the initially studied exemplars from each category (Anderson et al, 1994). The unsurprising result of this manipulation is that the exemplars practiced in the retrieval practice phase are remembered better at test (e.g., orange) than exemplars from an unpracticed category (e.g., oak), the retrieval practice effect. The more interesting result of this manipulation is, however, the memory *deficit* of the unpracticed exemplars of a practiced category (e.g., apple) compared to exemplars from an unpracticed category (e.g., oak), the RIF effect.

Retrieval induced forgetting has been documented in numerous naturalistic studies, including research involving classroom materials (Macrae and MacLeod, 1999), crime scene details (Shaw, Bjork, Handal, 1995), and conversations (socially shared RIF; Cuc, Koppel, Hirst, 2007; for a meta-analytic review, see Murayama, Miyatsu, Buchli, & Storm, 2014).

The mechanism by which retrieval induced forgetting operates is thought to be the competition between the exemplars of each category, which is resolved by the inhibition of the unpracticed exemplars (Levy and Anderson, 2002). In this case, forgetting, although counterintuitive, can be adaptive if it reduces demands on cognitive control that would otherwise be needed to suppress

competition from unnecessary competing memories (Bjork, 1989; Kuhl, Dudukovic, Kahn, & Wagner, 2007). Adaptive forgetting may therefore increase cognitive efficiency.

A real-world manifestation of the impact of retrieval induced forgetting on memory has been speculated to explain the positivity bias in autobiographical memory: the tendency to recall pleasant more than either unpleasant or neutral memories, a bias that increases over the lifespan (Mather & Carstensen, 2005). A speculative mechanistic explanation of the positivity bias is retrieval induced forgetting (Storm & Jobe, 2012b): throughout life, people encounter cues associated with both emotionally positive and negative memories, which compete with each other for activation; being motivated to remember positive events from their life, people retrieve the positive preferentially, which induces forgetting in the competing negative events, leading to the positivity bias effect (Storm et al, 2015).

iv. Intentional Forgetting

a. Directed Forgetting

A more deliberate set of mechanisms that enables memory's malleability are cognitive control-dependent: directed forgetting, suppression induced forgetting (Fig. A5a) and thought substitution (Fig. A5b). *Cognitive control* is the ability to flexibly control thoughts in accordance with goals.

According to the phenomenon of directed forgetting, people are able to intentionally forget information, making it less accessible (Bjork, LaBerge, LeGrand, 1968). The list method paradigm revealing the directed forgetting effect consists of, first, presenting participants with 2 lists of items to be studied; immediately after studying the first list, half of the participants are instructed to forget the List 1 they had just studied (forget condition), and the other half of the participants are instructed to remember List 1 (control condition); then, all participants are instructed to study List 2; finally, during the test phase, all participants are asked to recall both lists. The results of this paradigm reveal that, at test, participants in the forget condition recall fewer items from List 1 than participants in the control condition, revealing the influence of directed forgetting on memory.

These results have been replicated over different items and methods, with robust findings (for a review, see MacLeod, 1999). As for the brain mechanism at play, it has been found that intentional forgetting is associated with increased hippocampal activity. Moreover, brain imaging research investigating this phenomenon indicated that intentional forgetting depends on different neural structures than unintentional forgetting and intentional remembering, and emphasized the role of the frontal control processes in directed forgetting (Wylie, Foxe, Taylor, 2007).

b. Suppression Induced Forgetting

Cognitive control's application in memory has also been illustrated with an adaptation of the classical think/no think paradigm (Fig. A5a) (Anderson, 2001). This paradigm has been designed to study the ability to volitionally suppress retrieval of a memory when confronted with reminders. In a simple version of this paradigm, participants study cue-target pairs, and are then instructed to recall the target, whenever the cue is presented; then, participants are instructed to retrieve the target when presented with the cue for some of the trials (think trials), and to avoid retrieving the target when seeing the cue for other trials (no-think trials), while a third type of trials are not presented during this phase (baseline trials). During a final test, participants get all the cues again, and are instructed to recall the target for all of them. The think and no-think trials

are then compared to the baseline trials: the think trials show enhanced memory compared to baseline, caused by intentional retrieval, whereas the no think trials show a deficit in memory compared to baseline, caused by the intentional inhibition. The negative effect is called *suppression-induced forgetting (SIF*; Anderson, 2001). SIF and RIF are similar in the correspondence between the three types of trial-items created by the paradigms: the think items correspond to the RP+ items (rehearsed items), the no-think items correspond to the RP- items (suppressed items), and the baseline items correspond to NRP items (control items). The think items and RP+ are both rehearsed and experience a boost in recall compared to baseline/NRP trials. The difference between the two paradigms lays primarily in how the no-think/RP- items are suppressed: while the no-think items experience an intentional suppression as participants are instructed not to retrieve them when cued, the RP- items experience an unintentional suppression from practicing the competing RP+ items to which they are conceptually related. Despite the mechanisms being distinct, the result of both of these paradigms are comparable: no-think items are suppressed compared to baseline items (SIF), and RP- items are suppressed compared to NRP items (RIF).

SIF has also been found to hold for autobiographical memories (Noreen and MacLeod, 2013). The brain areas responsible for this suppression effect have been found to overlap with the areas involved in stopping reflexive motor actions (the right lateral PFC), suggesting that stopping actions and memories may be accomplished by a common inhibition process (Anderson et al, 2004). As for the neural mechanism behind this process, it has been found that the right lateral PFC reduces hippocampal activity during no think trials, which is what leads to suppression (Benoit and Anderson, 2012).

c. Thought Substitution

Finally, another mechanism by which memory can be controlled is *thought substitution* (Bergrstrom et al, 2009) (Fig. A5b). Building on the think/no think paradigm, researchers have modified the initial paradigm described above, by adding a between subject condition in which participants were instructed, for the no-think trials, instead of stopping retrieval, to retrieve an alternative target (redirect-thought condition). When comparing participants in the no-think avoid (SIF) condition to participants in the no-think redirect (Sub) condition, researchers found the same degree of memory suppression (Bergrstrom et al, 2009). However, the same outcome was accomplished through different brain mechanisms: as mentioned before, suppression by SIF is caused by the right lateral PFC decreasing the hippocampal activity, whereas suppression by substitution is caused by the left PFC increasing the hippocampal activation to retrieve alternative memories. Therefore, people have multiple deliberate methods (e.g., direct suppression, thought substitution) they can use to suppress an unwanted memory, thus reshaping their own memory through mnemonic influence.

In sum, the acquisition and forgetting mechanisms described in this section enable memory to be malleable and distortable, subject to updating, strengthening, or weakening, both incidentally and deliberately. The potential to control and change memory representations using these mechanisms has broad implications for the cognitive system, as it impacts not only memory processes, but also related, interlinked processes. Of these, of interest here, are reviewed processes belonging to three broad categories of higher order human cognition: emotion, reason, and action. While not necessarily exhaustive, these three categories could be considered

comprehensive models for any higher order cognitive research area not explicitly elaborated here.

3. Impacting High-Level Cognition by way of Mnemonic Accessibility

This section is a systematic review of the implications mnemonic influence has been found to have on other related but usually studied and depicted as independent mental processes: emotions, reason, and action. In each case, the mechanisms that contribute to this influence are described, and then relevant examples for which this influence is meaningful are elaborated. In the case of emotions, potential applications of the mnemonic influence are emphasized through the examples of PTSD and drug addiction. When diving into the impact on reasoning, the potential application explored is eyewitness testimony. Finally, in the case of action, the examples elaborated here are medical decision-making and consumption/savings behaviors.

a. Mnemonic Influence's Impact on Emotions

Emotions and memory are closely interlinked, as emotionally charged events experience a boosted encoding and a facilitated recall, in other words a better memory (Mueller & Cahill, 2010). Thus, manipulating one of these two processes will likely affect the other. The question addressed here is: can altering mnemonic accessibility affect emotions?

Emotional memories refer to memories formed and consolidated during emotionally positive or negative events (Hamann, 2001). When considering animal models, an emotional memory is a memory for an association between a stimulus and an emotional property, most extensively investigated as Pavlovian/classical conditioning of the fear response (Phelps & Schiller, 2013). A classic study that validated the possibility of manipulating an emotion by experimentally manipulating memory was conducted by Nader and colleagues (2000): the researchers first conditioned rats to associate an auditory stimulus to a fear response, and after one day, they reactivated the memory of the association, after which they administered into the amygdala a protein synthesis inhibitor, to disrupt the reconsolidation of the memory. The lateral amygdala is a sensible target for the drug injection, as the acquisition, storage, and expression of conditioned fear in animal models depend on the amygdala (for a review, see LeDoux, 2000). This procedure successfully impaired the long-term memory for the association, and therefore extinguished the emotional fear response to the stimulus (Nader et al, 2000).

In humans, fear conditioning is also realized by the pairing of a neutral stimulus (e.g., a red circle) with an aversive outcome (e.g., an electric shock) enough times, until the neutral stimulus alone triggers the fear response (Phelps & Schiller, 2013). The most common measure of the fear response in humans used in scientific studies is the skin conductance response, indicating the arousal of the autonomic nervous system (Fredrikson & Ohman, 1979). Fear conditioning in humans has been shown to rely on the same neural systems as described in animal models (for a review, see Phelps & LeDoux, 2005). However, since injecting protein synthesis inhibitors in the human amygdala is too invasive and unsafe of an experimental manipulation, most of the research on human emotional memories drug manipulations has been conducted using a beta-adrenergic blocker instead (propranolol), to disrupt amygdala's function (McGaugh, 2000). One successful such endeavor is documented in a study by Soeter and Kindt (2012a): two fear inducing stimuli (e.g., a spider and a gun) were paired with a shock, while a

neutral stimulus (e.g., a mug) was not paired with a shock; a day later, one of the fear relevant stimuli was presented to reactivate the memory for the association, followed by a dose of propranolol or placebo (there was also a no memory reactivation group). Another day later, all three stimuli were presented without shock (i.e., extinction trials), after which a fear memory reinstatement test was administered, measuring startle, skin conductance response (SCR), and explicit self-reported probability estimate of getting shocked on every trial (Soeter & Kindt, 2012a). The results showed a successful disruption of the startle response (but not of the SCR or probability ratings) in the reactivation followed by propranolol group, compared to the control groups, suggesting that the drug-induced memory manipulation successfully reduced the human emotional fear response acquired through conditioning.

Another experimental paradigm testing the effects of propranolol on the human conditioned emotional response was tested in the Phelps lab (unpublished, but described in Schiller & Phelps, 2011): human subjects were fear conditioned by being exposed to a colored square as they got mildly shocked, and a differently colored square without the shock; the following day, participants were shown the two squares again to activate the memory for the associations, and they were administered propranolol or placebo (a control group of participants were given propranolol without the memory reactivation); the following day all participants were presented with of the two squares without the shocks, as their skin conductance response was being measured. The conditioned response here is the difference between the SCR of the shock square association and the SCR of the no-shock square association. The results showed the hypothesized extinction of the fear response for the participants who received propranolol, and a strong fear response for the participants who received the placebo. However, this experiment also showed unexpected patterns that raised questions about the effects of this drug on human emotional memory: for instance, the group of participants who were administered propranolol without the memory reactivation also displayed an extinguished fear response, potentially suggesting that propranolol's action was broader, not just during reconsolidation; also, the extinguished response was only observed during the first trial of the post-drug phase, after which the response returned for all participants. Although this experiment's results were more challenging to interpret, its findings have been well-justified. For example, even though the implicit association between the stimulus and the shock depends on the amygdala (region targeted by propranolol), the explicit association depends on the hippocampus, so unless both brain structures are targeted, the memory for the association remains intact (LaBar & Phelps, 2005). Therefore, the emotional response will still be displayed, as explicit knowledge of the association is enough to elicit fear (Phelps et al, 2001).

However, fear conditioning through direct aversive experience is not the only way an emotional memory can be created. Another proposed mechanism for the acquisition of emotional memories is social fear learning, which assumes individuals learn fear responses by observing other individuals experiencing aversive situations (Olsson & Phelps, 2007). More concretely, observational fear learning is acquired through the exposure of an observer to a member of their species expressing distress when faced with an aversive stimulus, which produces a fear response in the observer. This ability has an adaptive function, and thus has been observed in numerous species such as birds, mice, and cows. In monkeys and humans this ability is most refined, as they are able to learn fear responses by observing facial expressions of other members of their species (Mineka, Davidson, Cook, Keir, 1984; Olsson & Phelps, 2004).

Human emotional memories acquired through mechanisms other than Pavlovian conditioning have also been shown to be subject to successful manipulations. Schwabe and

colleagues (2012) showed the effect of disrupting reconsolidation of episodic emotional memories, in a brain imaging study: first, participants were exposed to emotional and neutral scenes; a day later, they were administered a dose of propranolol or placebo, after which half of them were asked to mentally retrieve the scenes they had initially encoded; finally, a day later participants completed the forced-choice recognition test phase (Schwabe et al, 2012). The behavioral results revealed impaired recognition memory for emotional scenes in the reactivation-propranolol condition, compared to the placebo and the no-reactivation conditions. At the neural level, participants in the reactivation-propranolol condition showed increased activation in the amygdala and hippocampus when they correctly recognized the emotional scenes. This pattern was interpreted by the authors as necessary additional recruitment of these two regions given the impaired memory of the scenes caused by the administration of propranolol during reconsolidation (Schwabe et al, 2012).

Therefore, mnemonic influence has been shown to impact emotional memories, associated emotions, and associated emotional responses of not only fear conditioned associations, but also emotional episodic memories.

Applications in Post-Traumatic Stress Disorder (PTSD)

The idea that emotional responses could be affected by manipulating relevant memories has sparked interest for potential implications of this finding in alleviating symptoms of PTSD. PTSD was introduced in the DSM-3 in 1980, prior to which it was referred to as "war neurosis" (Donovan, 2010). PTSD develops as a person experiences a trauma, event during which endogenous stress hormones overconsolidate the memory of the experience (Pitman & Orr, 1990), creating an excessively powerful memory of the negative event (Brunet et al 2001). This memory is then so easily reactivated (as dreams or flashbacks) that it elicits intense conditioned emotional responses (Pitman, 1989).

Brunet and colleagues (2008) used a drug therapy technique as a memory manipulation to reduce the distress caused by traumatic memories: participants with chronic PTSD were first asked to describe their traumatic memory, after which they were administered a dose of propranolol or placebo in a randomized double blind design; a week later, they were asked to recall the traumatic memory again, while their physiological responses were being measured (e.g., heart rate, skin conductance, facial expression); researchers found smaller physiologic responses to the traumatic memory in the participants who received the propranolol compared to participants who received the placebo treatment (Brunet et al, 2008). This result showed the possibility of diminishing the emotional response of traumatic memories in human subjects, by disrupting reconsolidation with drug therapy.

This initial study was followed by a series of other studies reporting similar results (Brunet et al, 2011; Poundja et al, 2012). In these experiments instead of measuring physiological responses, the researchers measured PTSD symptoms, using the Clinician-Administered PTSD Scale (Blake et al, 1995). Also, instead of comparing a drug condition with a placebo condition, in these experiments researchers compared participants' PTSD symptoms pre and post treatment. Participants were first administered propranolol prior to being asked to retrieve their traumatic memory and during the memory reactivation (procedure repeated in 6 sessions). The main results of these experiments revealed decreased PTSD symptoms that lasted at least 6 months after the treatment, with some participants no longer even meeting the PTSD criteria anymore (Brunet et al, 2011; Poundja et al, 2012).

Beyond pharmacological attenuation of PTSD symptoms, they have also been tackled using physical approaches. Osuch and colleagues (2009) asked participants to generate lists of memories associated with their traumatic memory, after which they administered low frequency transcranial magnetic stimulation (TMS; Hoffman, et al, 2007) targeting the dorsolateral PFC, area involved in trauma retrieval (Rossi et al, 2006). Participants were administered 20 such treatments, after which they started displaying reduced arousal caused by their traumatic memories, compared to placebo participants (Osuch et al, 2009).

These promising initial investigations have sparked considerable interest and optimism in the idea that mnemonic influence could be used to further understand and potentially even mitigate PTSD symptoms; however, this area of research needs to reconcile some of the current inconsistencies in findings (Phelps & Schiller, 2013). Of course, this is a gradual but slow process, as investigators need to overcome several outstanding challenges: the difficulty of drawing an analog of human PTSD in animal models (models which would allow for experimentation at a higher speed), the invasive nature of the research methods, and the ethical impediments and pushbacks (discussed in more detail in the Ethics section). Despite these challenges, the clear message of this research area is that mnemonic influence's impact on emotional responses could be used to alleviate PTSD symptoms, which is a very valuable discovery, given the high prevalence of this disorder (~10% of the US population; Shalev, 2009).

Applications in Drug Addiction and Relapse

Targeting emotions through mnemonic influence has also been proven relevant in the sphere of drug addiction and relapse. The investigation of this association began after the discovery that the reinforcing effects of drug self-administration do not only depend on increased dopamine in the nucleus accumbens and associated areas (Wise, 2008), but they also depend on environmental stimuli, associated through classical conditioning (Gawin & Kleber, 1986; O'Brien et al., 1998). Thus, disrupting the conditioned responses to drugs could be a good way of treating addiction noninvasively (for a review, see Everitt, 2014).

In animal models, propranolol administration to disrupt reconsolidation successfully attenuated the reinforcing properties of conditioned cocaine-associated stimuli, thus decreasing their likelihood of triggering the addiction-related behaviors (Lee et al, 2006, Milton et al, 2008). Moreover, alcohol addiction has also been studied in the context of memory manipulation therapy, in a study that directly tested the efficiency of such treatment on alcohol addiction in rats (Schramm, Everitt, Milton, 2015).

In humans, the literature is less extensive, but studies describe encouraging results. Xue and colleagues (2012) demonstrated an application of mnemonic influence in treating addiction with a study conducted on inpatient detoxified heroin addicts: first, participants' baseline cue-induced heroin craving (i.e., visual analog scale, heart rate, blood pressure) was tested; during the following two days, participants' memory of the drug was reactivated, after which they underwent extinction training (i.e., exposure to heroin-related cues); a separate control group was administered the extinction training without the memory reactivation, and another control group was administered the extinction training 6-hours after the memory reactivation; finally, participants' craving was assessed on the 4^{th}, 34^{th}, and 184^{th} day after the experiment began. The results revealed that craving was attenuated only for the participants who went through extinction training immediately after the memory reactivation (Xue et al, 2012).

Another successful memory manipulation impacting addiction has been documented in a study by Amiaz and colleagues (2009): the researchers showed participants smoking cues to reactivate their memories of smoking, after which they administered TMS for 10 days, targeting the dorsolateral PFC (Amiaz et al, 2009). The immediate results were promising, as cigarette craving and consumption were successfully reduced, but this reduction did not hold over time suggesting that targeting relapse is just as important and challenging as tackling addiction. Researchers have recently taken on this challenge as well, and promising results addressing relapse have already been found in animal experiments (Luo et al, 2015).

Thus, memory seems to play a role in the addiction circuit, given the classical conditioning nature of addiction acquisition. This relationship has been explored with promising initial results revealing the potential to intervene and weaken many types of addictions, in both animal models and human subjects. This area of research is still ongoing, with the goal of finding ways to extinguish, not just temporarily disrupt addictive tendencies. Using mnemonic influence to treat addiction, just like in the case of PTSD, would be an immeasurably valuable tool for society, given the high rate of people experiencing this disorder (~9.4% of the US population in 2013, and 5.4% of the world population) (NIH, 2013; WHO, 2008), the high cost of current treatments ($600 billion annually in the US alone) (NIH, 2018), and the low rate of individuals with addiction currently receiving treatment for their condition (~10% of addicts in the US) (SAMHSA, 2017).

b. Mnemonic Influence's Impact on Reasoning – Beliefs

Another cognitive process closely interlinked with memory is belief endorsement. Belief is defined as the "confidence in the truth or existence of something not immediately susceptible to a rigorous proof" in Webster's dictionary. Using this definition, Schacter and Scarry (2001) argue that memory is a kind of belief – the belief about the past. Moreover, the researchers also raise the idea that just like memories are shaped by beliefs, beliefs are also shaped by memories (Schacter & Scarry, 2001). So, if memory and beliefs are such closely interlinked concepts, what are some implications of mnemonic influence on belief endorsement?

The most widely documented instance by which a memory manipulation impacts beliefs is referred to as the illusory truth effect (for a meta-analysis see Dechêne, Stahl, Hansen, Wänke, 2010). The illusory truth effect is the increase in belief endorsement for information people remember having encountered before. For example, Begg and colleagues (1992) presented participants with statements qualified as either true, false, or with no qualification; then, after a delay, participants were asked to indicate the believability of these statements as well as the believability of new statements. The results showed that participants judged the no-qualification statements as true more often than the novel statements, the only difference between the two types of statements being participants' familiarity with them. Moreover, the results also showed a tendency to judge the statements qualified as false more often as true than as false, indicating the fact that participants failed to recollect whether the statements were presented as true or as false, and instead, relying on familiarity, judged them as true (Begg et al, 1992). Thus, an increased mnemonic accessibility to a statement leads to increased believability of the statement. Moreover, the illusory truth effect has been shown to arise because of the familiarity caused by repetition, not because of the repetition itself. Since information retrieved from memory is more familiar than novel information, the ease with which a belief comes to mind gives the illusion of truth. The effect of memory retrieval on the illusory truth in the absence of explicit repetition has

been shown in an experiment by Ozubko and Fugelsang (2014): participants were presented with a factual statement and an inference statement that followed from the factual one, in 4 conditions; in the control condition, the factual and inference statement were presented simultaneously, participants being instructed to rate the accuracy of the inference statement; in the two-repetition condition the factual statement was presented twice, once before the inference task, and again alongside the inference statement; in the four-repetition condition participants saw the factual statement three times prior to seeing it again during the inference task; the retrieval condition was similar to the two-repetition condition, with the only difference being that the factual statement was only presented prior to the inference task, and omitted during the task, participants still having to make their accuracy rating of the inference statement based on the factual statement. The results showed a significant difference between the control and the four-repetition condition – replicating the illusory truth effect. More importantly, the retrieval condition showed the highest illusory truth effect of the four conditions, significantly higher than the control condition. An implication of these results could be that information retrieved from memory is more fluently processed than directly perceived information. The main addition of this experiment however, is the demonstration that the illusory truth effect can occur in the absence of explicit repetition, through memory retrieval (Ozubko & Fugelsang, 2014).

Thus, the illusory truth effect shows that activating memory increases believability, but if one wants to conclude unequivocally that memory impacts beliefs, they should also show that downregulating memories results in decreased believability. To investigate this conjecture, Vlasceanu and Coman (2018) studied the impact decreased mnemonic accessibility of statements has on statement believability. Using the selective practice paradigm (typically used in RIF experiments) the mnemonic accessibility of some beliefs was increased, while the accessibility of others was decreased. Participants first rated their degree of belief endorsement for child rearing statements across several categories; then, in the second phase, they were exposed to an audio recording in which they heard mentioned some of the statements from half of the categories (practiced items). This procedure allowed for the emergence of 3 types of items: practiced items, unpracticed items within practiced categories, and unpracticed items outside the practiced categories. In the third phase, participants were asked to recall all the initial statements, in an incidental cued-recall task; finally, they were asked to reevaluate the degree of belief endorsement for the original statements. The selective practice paradigm led to an increase in mnemonic accessibility for the practiced items, and a decrease in mnemonic accessibility for the unpracticed within-category items, compared to the control items (the unpracticed outside-category items). The results of this procedure showed that the beliefs that became more mnemonically accessible exhibited an increase in believability, while the beliefs that became less mnemonically accessible exhibited a decrease in believability (Vlasceanu & Coman, 2018).

A special kind of belief worth considering here are beliefs about memory, characterized by the vividness and confidence in one's memory of a past event, not necessarily correlated with the objective accuracy of the recollection. The first to show the dissociation between the accuracy and confidence in one's memory were Talarico and Rubin (2003), in a study conducted after the 9/11 attack. Participants were asked to record the memory of first hearing about the attack the day after it happened, and then again either 1, 6, or 32 weeks later. The results of this investigation showed that while accuracy in the initial memory declined over time, the belief in the accuracy of the memory (confidence/vividness) did not decline (Talarico & Rubin, 2003). This initial result drew attention to the false belief phenomenon in autobiographical memory.

The false belief phenomenon was also documented by Hirst and colleagues (2009): citizens were asked to recall the episode when they first heard about the 9/11 attack at different timepoints – from a few weeks, to 3 years after the attack. The results of this study showed that 37% of people changed details of their stories after one year, and 43% of people changed the details after 3 years. Despite this decrement in accuracy, participants remained highly confident in their memories, believing they are accurate. The researchers attributed the memory distortion source to media coverage of the events (Hirst et al, 2009): the original accurate memory was reactivated and thus became vulnerable to distortions every time people were reminded of the event, most frequently by the media; with every new reactivation of the memory, details from external sources were adopted, thus incorporated into the original memory. Hence, memory distortions can lead to the formation of false memories, which in turn create false beliefs about past events. In sum, a stronger memory elicits a strong belief, a weaker memory elicits a weak belief, and a distorted memory elicits a false belief.

Applications in the Legal Context – beliefs about memory

It is essential to consider the impact of memory on belief in the case of eyewitnesses' testimonies. Eyewitnesses reports are highly influential in crime trials, as in many cases the verdicts depend heavily on these testimonies (Loftus, 1996). This is still the case today in many jurisdictions around the US, even though a few of them have started implementing procedures to make sure verdicts are not based on testimonies alone, instead encouraging corroborative evidence (Lacy & Stark, 2014). Establishing the reliability of eyewitness's reports has been the priority of many researchers and legal agencies, interest that was further reinforced by the Innocence Project (2017), a mission that uses DNA testing to exonerate wrongly convicted prisoners, convictions caused by eyewitness misidentifications. Such misidentifications have been documented to have played a role in a shocking 70% of the 353 convictions of innocent suspects exonerated by DNA evidence since 1989 (Innocence Project, 2017). So why and how do misidentifications happen?

One intensely investigated mechanism through which misidentifications can occur is the misinformation effect: a memory is distorted by related misleading information, a direct application of memory updating through mnemonic influence. An example of how this effect may unfold in the legal sphere is the following: the eyewitness's memory of the face of the perpetrator is activated during interrogation, thus the memory becomes unstable and susceptible to distortion (weakening, strengthening, or updating); at this point, if the eyewitness is presented with a picture of a potential suspect, as is common practice in the case of a lineup (Wells & Olson, 2003), the initial memory of the face can get updated to include the new information, thus the suspect's face can bind to the initial memory. Since this process is unconscious, after reconsolidation is completed, the eyewitness will not only misidentify the potentially innocent suspect as the perpetrator, but also believe with high confidence in his distorted recollection, especially if he gets post-identification feedback (e.g., "Good, you identified the suspect"; Semmler, Brewer, Wells, 2004). In this example, this misidentification is caused by a memory manipulation through mnemonic influence, and the false confidence is caused by a source monitoring failure, a common failure of the memory system in which the origin of a memory is reassigned to a different event (Johnson, Hashtroudi, Lindsay, 1993). To more intuitively demonstrate the source monitoring phenomenon, a more commonly experienced example is that of people believing having seen something they only read about in text, experience caused by

people's tendency to engage in visual imagery during reading (Belli, Lindsay, Gales, McCarthy, 1994; Intraub & Hoffman, 1992; Zaragoza et al, 1997).

One of the first studies to experimentally illustrate the misinformation effect, showed how suggestibility has the power to distort a memory and create a false belief. Participants were exposed to 30 slides representing an auto-pedestrian accident: half of the participants saw a car heading towards an intersection with a stop sign, while the other half saw the same scenario with a yield sign instead; the story ended with the car taking a right turn and running over a pedestrian crossing the street at a crosswalk; after viewing these slides, participants answered 20 questions, of which of interest was "Did another car pass the red Datsun while it was stopped at the *stop* sign?". Half of the participants answered this question, while the others were asked "Did another car pass the red Datsun while it was stopped at the *yield* sign?"; this experimental design produced a condition in which participants received consistent information, and a condition in which participants received inconsistent information between the initial story and the suggestive question; participants were then asked to complete the last phase of the study – a two forced choice recognition test; the choice of interest was between the pair of images depicting the car stopped at the yield/stop sign. The results of this experiment showed that recognition of the original story was impaired by the suggestive power of the inconsistent question (over 80% of subjects responded incorrectly in the inconsistent condition), uncovering again the reconstructive nature of human memory (Loftus, Miller, Burns, 1978).

This effect of suggestibility on false memory formation or on memory distortion has been found in hundreds of studies over the past 40 years, across many types of situations (e.g., face identification, car speed estimation, lost at the mall memory implantation etc.), effect strongly holding even in the case of experts, or highly trained individuals (for a review, see Loftus, 2005). Moreover, explicit warnings about the influence of misleading information have been shown to not eliminate the effects of misinformation on memory, even though they reduced it (Ecker, Lewandowsky, Tang, 2010).

Selective forgetting is another mechanism by which mnemonic influence plays a role in the eyewitnesses' testimonies. Retrieval induced forgetting affecting witnesses' memories is likely, given the typical selective cued recall they are subjected to during an interrogation. Thus, a complete recall is unlikely to be achieved during the initial questioning, and only a subset of the details of the event is actually recalled (Storm et al, 2015). In support of this claim, retrieval induced forgetting has been found in every eyewitness context in which it has been investigated in laboratory experiments: narrative descriptions (Migueles & García-Bajos, 2006), pictures (MacLeod, 2002), or videos (Camp et al., 2012). A classic example of an empirical finding supporting the role of retrieval induced forgetting in eyewitness testimonies is documented by Camp and colleagues (2012): participants saw a video of two offenders committing a robbery; following the video, participants were asked questions about half of the characteristics of one of the two perpetrators (e.g., "What kind of haircut did the offender have?"). The results of this experiment showed that the selective retrieval practice of some characteristics of one perpetrator caused forgetting of the other characteristics of the same perpetrator (e.g., color of his pants), and also caused forgetting of the practiced characteristics in the other perpetrator (e.g., haircut of the other perpetrator) (Camp et al, 2012).

However, even though the current view among the scientific community is that eyewitness testimony is unreliable, researchers such as Wixted, Mickes, and Fisher (2018) are arguing that, if used under proper conditions, eyewitness testimonies can be highly informative and should not be discarded as evidence in trials. In a recent article, Wixted and colleagues made

a parallel between eyewitness's memories and DNA evidence, suggesting that both types of evidence are reliable before contamination occurs. The authors outline conditions under which eyewitness memories can be trusted, such as: witnesses should not be exposed to contaminated information prior to their interrogation, their memories should only be probed for the first time, their confidence level should be assessed during this initial interrogation, suggestive questions or comments should not be directed toward the witness during this interrogation (Wixted, Mickes, Fisher, 2018).

Thus, beliefs about events people witness are likely accurate initially, when the memory of the event is not contaminated, but after the memory is reactivated and becomes vulnerable to suggestibility and distortions, false memories are likely to shift these beliefs with major consequences in the legal domain. The effect of mnemonic influence in this case is not a desirable one for society, as it would be preferable to be able to trust eyewitnesses' recollections to make sure perpetrators, and not innocent people, are the ones convicted for their own crimes. However, when considering the alternative case, in which instead of flexible, memory would be entirely accurate, the eyewitness would be holding on to a perfect memory of the witnessed crime forever. Even though this scenario would provide trials with more accurate testimonies, the downstream consequences for the witnesses would be overwhelming and damaging. Thus, from the perspective of those witnessing disturbing events, the malleable nature of memory that allows their memories to fade is a desirable feature of the cognitive system.

c. Mnemonic Influence's Impact on Decision-Making

Memory impacts decision-making directly, but also indirectly by impacting other cognitive processes such as emotions or reasoning, which in turn impact decisions (for a review see Weber & Johnson, 2009).

In animal models, the impact of memory on decisions can be observed, for example, as navigational decisions based on stored memories: this behavior relies on the representation of the external world in memory, referred to as the "cognitive map" (Tolman et al, 1946; Tolman, 1948). Cognitive maps are thought to operate by representing both past experience (retrospective path) and future experience (prospective path) in the hippocampus, at the same time. This mechanism was supported by a rodent study in which the simultaneous coding of retrospective and prospective led to choices in continuous T mazes (Catanese et al, 2014).

In human research, decision making is the cognitive process resulting in the deliberate selection of an action. The impact of mnemonic influence on decision-making occurs according to the processes triggered as a memory is retrieved: its accessibility increases, and its content becomes vulnerable to distortion (Weber & Johnson, 2009). The effect of manipulating memory on decision-making has been studied by Johnson, Häubl, and Keinan (2007) who manipulated the accessibility of objects' characteristics (e.g., advantages and disadvantages) to impact the decision of attributing a value to each object. Increasing the accessibility of a mental representation through priming has also showed outstanding implications for decision-making (Mandel & Johnson, 2002). This has been demonstrated by Mandel and Johnson (2002) in an online experiment in which they manipulated the background picture and color of a web page, which resulted in predictable differences in participants' choices. A special case of priming influencing decisions is the recognition-primed decision model (RPD; Klein, Calderwood, Clinton-Cirocco, 1986), describing how people use their experience to inform reactions to specific situations. This model was developed based on interviews with fireground commanders

about their reactions to challenging incidents (Klein, 1989). Priming of autobiographical memories, which is merely a reactivation of a representation, was also shown to impact decisions in a study conducted by Kuwabara and Pillemer (2010) in which college students who were primed with a personal college memory were more willing to donate, attend a class reunion, and recommend the university, compared to participants who were not primed.

The role of mnemonic influence in shaping behaviors has also been demonstrated using the selective practice paradigm (Bjork et al, 1994). Iglesias-Parro and Gomez Ariza (2006) showed participants the descriptions of two candidates for a job: they each had 3 positive traits and 3 irrelevant traits; then, participants were prompted to retrieve the irrelevant traits of one of the candidates; finally, participants were asked to choose their favorite candidate for the job, after which they were administered the final cued recall test. The results showed that participants selected more often the candidate whose irrelevant traits hadn't been practiced during the selective practice phase. This result suggest that the selective practice of the irrelevant traits induced forgetting in the positive traits of that candidate, which made him/her a less preferred option.

Moreover, memory has also been found to impact decisions through familiarity, as it has been proposed that choice selection between various products depends on the familiarity with the products (Park & Lessig, 1981). According to this relationship, the more familiar a product is, the higher the preference for the product and likelihood of choosing it. For example, Ward, Goodman, and Irwin (2013) showed that familiarity with a song was the best predictor for the decision of choosing that song (Ward, Goodman, Irwin, 2013). The theoretical explanation of this relationship dates back to Zajonc's (1968) mere exposure effect, revealing that exposure to a stimulus increases affect towards it. This effect is supported by the perceptual fluency theory: the number of times one is exposed to a stimulus is correlated with the ease of comprehension of the stimulus, which leads to preference due to its ease of processing (Jacoby & Dallas, 1981). Thus, the stronger the memory of the stimulus is, the more likely the choice of that stimulus becomes. But perceptual fluency is not only a factor in product choices, it also plays a role in verdict decisions: in a study by Pennington and Hastie (1988) participants were presented with explanatory summaries of evidence in criminal trials and were asked to make verdict decisions informed by the available pieces of evidence; the results showed that the coherence of the evidence summaries had a causal impact on the decisions participants made (Pennington & Hastie, 1988). Familiarity has also been studied in the context of memory heuristics impacting decisions: for example, the recognition heuristic is a simple rule by which, given the choice between two alternatives, the recognized one is chosen over the unrecognized one. This rule has been exemplified by experiments conducted by Goldstein and Gigerenzer (2002) using a task of having to choose the larger of two cities.

The impact of memory on behavior has been observed and documented in many domains, most of them relying on a generic mechanism by which increased mnemonic accessibility of a concept leads to increased likelihood of engaging in a behavior consistent with that concept. Of the behaviors for which this mechanism has been observed and documented, the next section expands the cases of medical decision making (Coman et al, 2013) and consumer choices (Bettman, 1979).

Applications in Medical Decisions

The increased accessibility of, for example, messages against vaccination, can influence parents' decisions to not vaccinate their children (for a review, see Bolton, Memory, McMillan, 2015). One potential mechanism for this relationship is parents' repeated exposure to misinformation regarding vaccination increases their beliefs about the dangers of vaccination (i.e., illusory truth effect), which in turn can lead them to make the decision of not vaccinating their children (McCauley, Kennedy, Basket, Sheedy, 2012).

The importance of memory in influencing decisions has been empirically illustrated in the case of medical decision-making patterns displayed by patients, in an experiment conducted by Redelmeier, Katz, and Kahneman (2003): participants' memory of a painful medical procedure (i.e., patients who underwent a colonoscopy) was manipulated such that they remembered the procedure as less painful, less aversive, and less unpleasant, compared to a control group (controlling for the actual degree of pain reported during the procedure). This memory manipulation was achieved by adding a short interval at the end of the standard procedure in which even though the procedure was over, participants thought it was still ongoing. This manipulation was based on the observation that the memory of pain during a procedure depends on the last few minutes of the procedure (Redelmeier & Kahneman, 1996). The results of this experiment showed an increase in the rate of returning for another invasive procedure in the group of patients who were manipulated to remember the procedure as less painful (Redelmeier, Katz, Kahneman, 2003). This study reveals the importance of memory for medical decisions, and more specifically, the possibility of impacting medical decisions through mnemonic influence.

Another instance in which manipulating memory has been found to have an impact on medical decision-making is a study conducted by Coman, Coman, and Hirst, (2013): the researchers manipulated the mnemonic accessibility of medical information (i.e., advantages and disadvantages of different treatment options) using the selective practice paradigm (described in chapter 3.b.) such that some pieces of information were more accessible, and others were less accessible, compared to a baseline; the results of this study showed that decreasing the mnemonic accessibility of certain features of a medical treatment (e.g., advantages) negatively impacts the decision to choose the corresponding treatment (Coman, Coman, Hirst, 2013).

In sum, the possibility of impacting medical decisions through mnemonic influence has been experimentally demonstrated, with the intentions of uncovering ways in which people can be influenced to make better health-related decisions, as advised by health specialists (e.g., agree to minimally invasive procedures when necessary). Thus, mnemonic influence's impact on behavior can be a valuable tool for society when used under principles of benevolence, as also emphasized in the following section.

Applications in Consumption/Saving Behaviors

Understanding the malleable nature of memory, researchers have demonstrated the possibility of intentionally manipulating consumers' memories of product experiences. For example, Braun (1999) showed the impact of postexperience advertising on consumers' memories of their experience: participants were randomly assigned to 3 conditions and asked to drink a sample of orange juice tasting either good, mediocre, or bad (the bad juice contained vinegar and salt); an hour later, half of the participants in each condition were presented with an advertisement suggesting the juice had an excellent taste, after which they were asked to recall their experience tasting. The results showed that participants who tasted the bad juice after which they were

exposed to the advertisement, recalled having tasted a more flavorful juice than participants who were not exposed to the advertisement (Braun, 1999), revealing the impact commercials can have on consumers' memories. Similarly, memory distortions have been shown to impact actions by Bernstein and Loftus (2009), who showed how false memories lead to behavioral outcomes.

In the marketing literature, it is recognized that memory plays a major role in consumer choice (Bettman, 1979). Consumer choices are often made in accordance with individuals' preferences, which are stored in memory. This means that preferences are (re)constructed, rather than simply retrieved at any given moment (Lichtenstein & Slovic 2006). This dependency of preferences on memory renders preferences malleable and subject to distortions and biases (Thaler & Sunstein 2008). This constructive view of preferences suggests that consumers focus on the aspects emphasized by the immediate context. In doing so, they make choices consistent with the most accessible consideration, and not necessarily with well-defined preferences, which leads to inconsistent decisions (Bettman, Luce, Payne 1998). For example, it was found that increased accessibility of a brand name impacts the decision to choose that specific brand (Biehal & Chakravarti, 1983). This finding led to the coining of the term *brand equity*, term referring to the positive association between consumers' memories for a product's brand, and their loyalty towards the brand (Stijn, van Osselaer, Alba, 2000). Advertising researchers also documented the impact of repeated exposure (i.e. increased mnemonic accessibility) to a brand on consumers' choices (Krugman, 1986), the memorability of the brand name (concrete physical characteristics of a product vs abstract brand names) (Robertson, 1987), as well as the effects of classical conditioning on choices (Gorn, 1982), amongst others.

Switching gears from consumption to savings, mnemonic influence has proven useful at persuading savings decisions across interventions aimed at nudging people to save part of their income. Nudging, also referred to as "choice architecture", refers to the "strategic changes in the environment that are anticipated to alter people's behaviour in a predictable way, without forbidding any options or significantly changing their economic incentives" (Bucher et al, 2016). Saving behaviors is a very active area of research given the problematic reality that many people save little or nothing at all (Lusardi, 2003), especially in the United States (Kotlikoff, 1989). One notable intervention to increase saving behaviors has been conducted in Colombia, targeting low-income youth. Participants were followed over the course of 12 months, during which they were sent monthly or semimonthly text messages containing savings reminders in the experimental conditions, and monthly financial education messages or no messages in the control conditions. The results showed that account balances increased by 28% in the monthly-reminders condition and by 43% in the semimonthly condition compared to the control conditions, results that lasted 8 months after participants stopped receiving messages (Rodríguez & Saavedra, 2015). Thus, the more savings reminders participants got (increased accessibility of the savings option) the more they actually engaged in saving behaviors, an effect that once again demonstrates the beneficial effect of mnemonic influence's impact on decision making.

In sum, memory manipulations (i.e., differing levels of mnemonic accessibility) have a significant documented impact on consumers' actions, considerably influencing people's decisions and choices. In a similar fashion to the medical decision-making implications, the possibility of nudging citizens in the direction of optimal consumption/saving behaviors can be a powerful tool for governments, with significant potential benefits for the population, assuming the benevolence of the policy designers. The potential of behavioral science to aid in solving a wide range of policy problems has been suggested by many (Halpern, 2015; Ly, Mazar, Zhao, & Soman, 2013; Sunstein, 2013; Thaler & Sunstein, 2008; The World Bank, 2015) and also already

adopted as supplement or replacement of older methods of incentivizing desirable behaviors, first by the United Kingdom in 2010, followed by Australia, Germany, the US, and others (Obama, 2015). Using this tool is essential for community prosperity, and should be used in domains in which people are prone to make decisions that are detrimental to their own or to the public welfare, such as: saving for retirement (Börsch-Supan, 2004), obesity control (World Health Organization, 2013), public transport usage (European Commission, 2011), and insurance enrollment (Kunreuther & Michel-Kerjan, 2011).

4. Ethics of Mnemonic Influence

The President's Council on Bioethics (2003) cited the Lotus Eaters from Homer's Odyssey, who lost the sense of self when their memories were erased, to suggest the potential devastating implications of memory manipulations (Corlett & Taylor, 2013). The ethical question triggered by treatments that involve mnemonic influence is a sensitive one, especially in instances in which consent is not straightforward. For instance, when considering the potential mnemonic influence might have in treating patients with maladaptive beliefs (e.g., false, dangerous, delusional), many ethical questions are raised, since these people do not realize their beliefs are pathological and these beliefs further contribute to their sense of self (Hagen, 2008). In this case, is it ethical to manipulate their memories if they do not consent to the treatment? One common answer usually invoked by health practitioners is that coercion is necessary and justified when used for a person's own good (i.e., paternalistic justification) (Olsen, 1998). The argument behind this line of reasoning is that a lack of decision-making competence justifies coercion.

Whether manipulation falls under the umbrella of coercion or not is also a point of debate: under Beauchamp and Childress's (2001) definition of coercion ("credible and severe threat of harm to force or control another"), manipulation is actually regarded as non-coercive, even though others do consider manipulation as a form of coercion (Curtis & Diamond, 1997; O'Brien, 2003), or subtle coercion (Lutzen, 1998).

However, even in cases in which consent is straightforward, ethical issues have still been invoked. For example, in the case of PTSD or other similar disorders in which patients consent to therapeutic forgetting treatments, the loss of personal identity, mendacity, stagnation, or intolerance toward states of distress in both the self and in others (Evers, 2007), have given this therapeutic approach a controversial dimension. Evers argues that "a mature adult must cope and not seek, for example, to escape unpleasant memories for the sake of well-being". Moreover, in the case of using therapeutic forgetting to treat soldiers with PTSD, she raises the point that helping veterans forget what they have been through will necessarily also imply helping them forget what they have done to others, which, she argues, will lead to even more violent acts, as the cost of remembering the committed violence will have been be diminished (Evers, 2007). A similar argument was emphasized by Judy Illes in 2013. Concerned about humanity's collective memory and collective identity, Illes challenged the idea of manipulating memories: "What would happen to stories about the Holocaust, or about the genocide in Rwanda, or the civil war in Syria? Would future generations still be able to understand what happened to their ancestors?" (Costandi, 2013). Thus, even when used with good intentions, for a noble cause, and with beneficial outcomes for the individual, mnemonic influence could be interpreted as detrimental for the larger society.

The ethics of manipulating people for their own benefit has also been considered in domains other than mental healthcare. For example, in the domain of politics, philosophers

Daniel Hausman and Brynn Welch discuss the ethics behind policies that manipulate people's decisions-making process to ensure they choose the option that most benefits them, in an article titled "Debate: To nudge or not to nudge", invoking once again the concept of paternalism (Hausman & Welch, 2010). While Thaler and Sunstein (2008) argue that libertarian paternalism is nonintrusive, Hausman and Welch counterargue that point claiming that shaping others' choices even if for their own benefit is "alarmingly intrusive" (Hausman & Welch, 2010).

The ethics of manipulability has also been extensively debated in the marketing domain. Though many argue the role of marketing is to meet consumers' needs, the ethics of the means of achieving this goal have been called into question by many others, especially when the manipulations are designed to act at a subliminal, unconscious level. For instance, Vance Packard's 1957 *The Hidden Persuade*rs book brought the idea that marketers manipulate consumers' behaviors in subliminal ways, into public attention and debate, making consumers suspicious of advertisers and marketers. Later, Hanson and Kysar (1999) coined the term *market manipulation* to discuss the exploitation of cognitive limitations of consumers by companies, as well as consumer autonomy and welfare.

Offering a more temperate view of the ethics behind using memory manipulation, Elsey and Kindt (2016) argue that manipulating memory, for instance during reconsolidation, as so far investigated, has a negligible probability of having a detrimental or ethically questionable effect (e.g., affecting the wrong memory, losing an autobiographical memory, or losing relevant emotional responses). The authors further claim that even though misuses and abuses of these practices are technically possible, they are unlikely to even work. Considering the example of disrupting a soldier's aversion to torture people, the authors dismiss such a possibility, stating that the act of imagining such extrapolations of scientific findings does not make them readily achievable (Elsey & Kindt, 2016).

In sum, many have offered their views on the ethics of mnemonic influence, both in favor and against using memory manipulation techniques therapeutically or to nudge choices. On one side, medical practitioners are hopeful such techniques could improve the quality of life of their patients by alleviating their symptoms, and potentially even cure their conditions (Olsen, 1998). From a very different angle, philosophers are terrified by the long term societal level implications of the use of mnemonic influence, invoking concepts such as losing personal identity, altering humanity's collective memory, or creating remorseless soldiers that commit atrocities, to warn against the use of such methods (Evers, 2007; Costandi, 2013). From yet another angle, researchers investigating memory manipulation mechanisms and economists, caution against letting imagination and fiction extrapolate scientific findings to create daunting scenarios, and suggest to instead consider the beneficial implications of the findings for society, assuming benevolence (Elsey & Kindt, 2016; Thaler & Sunstein, 2008).

Thus, even though consensus is hard to reach on such a controversial topic given its sizeable potential impact on a multitude of domains, a cautious yet optimistic construal of mnemonic influence seems most constructive at the moment. To sketch a space in which memory manipulation could be used responsibly, the recommended ethical guidelines that should be followed during such an intervention are benevolence, consent, and fairness (adapted from Beauchamp & Childress, 2001). First, benevolence refers here to both the *do no intentional harm* principle, and the *beneficence* principle – seek benefits for those undergoing the intervention. Second, the consent principle refers to the idea that during the intervention people should still be allowed to make informed and *voluntary decisions*. Third, fairness refers here to *equal* allocation of potential benefits from the intervention. These guidelines imply mnemonic

influence would only be used with good intentions, with the permission of those experiencing it, and uniformly, avoiding the formation of advantaged or disadvantaged groups. Assuming these considerations are being met, ethical concerns surrounding mnemonic influence, such as consent disputes, ill intentions fears, or marketing and policy skepticisms, would be assuaged. Mnemonic influence would be used responsibly and efficiently as a powerful tool that could better our society.

5. Conclusion

Research in psychology and neuroscience has made incremental advances in uncovering the mysteries behind memory influence in real life. A burgeoning body of work conducted over the past few decades, has greatly contributed to the understanding of the mechanisms, potential implications, and ethics of mnemonic influence.

First, to understand the mechanisms behind mnemonic influence, one needs to accept the reconstructive nature of memory. In the words of Frederic Charles Bartlett: "Remembering (…) is an imaginative reconstruction, or construction, built out of the relations of our attitude towards a whole active mass of organized past reactions or experience …" (Bartlett, 1932). Memory is a reconstructive process, subject to manipulations. The mechanisms identified that allow for the malleability of memory belong to one of two categories, acquisition and forgetting processes. Each of the two has both natural, involuntary (e.g., decay, consolidation) but also induced and/or voluntary (e.g., retrieval induced forgetting, reconsolidation) mechanisms by which memories are or can be altered.

Second, to understand the implications of mnemonic influence, one needs to also know that memories are not stored in isolation, instead, they integrate into complex associative networks (Debiec, Doyere, Nader, LeDoux, 2006; Levy & Anderson, 2002). Thus, the mechanisms that enable memory's malleability have outstanding implications for many cognitive processes, of particular interest here being emotion-level, reason-level, and action-level processes. Each one of these processes, in turn, has remarkable applications at the individual (e.g., PTSD, addiction) and societal levels (e.g., legal system, consumer or medical decisions), a few examples of which are expanded in the present article.

Finally, this review concludes by emphasizing some of the ethical arguments addressed in support or against the use of mnemonic influence not only therapeutically, but also more broadly, as nudging better decisions, and proposing some guidelines under which mnemonic influence can be used responsibly.

a. Future directions: Research Trajectories

Although much has been discovered so far in the domain of mnemonic influence, a lot more remains to be addressed. For example, research has pointed to a few implications of performing memory manipulation, but the exact boundary conditions of these implications are yet to be established. Thus, even though some effects have been documented under specific circumstances (specific context, cue, memory age, memory strength, duration of reminder, etc.), we are still unaware of their exact powers and limitations (Treanor, Brown, Rissman, Craske, 2017). For instance, we know that older and stronger memories are less susceptible to modifications during reconsolidation (Wichert, Wolf, Schwabe, 2011), but most of the boundary specifications are still unanswered questions (Treanor et al, 2017). For example, how would mnemonic influence propagate in larger social networks? That is, how far would an individual level mnemonic

influence reach in the individual's social network, in what direction would it preferentially extend, under what circumstances would it even propagate, for how long, with what strength, etc.? Pioneering work in this direction has been conducted to investigate mnemonic convergence properties and describe how information spreads in social networks (Coman et al, 2016). Coman and colleagues (2016) manipulated the conversational network structure of laboratory-created communities and measured the properties of propagation of mnemonic reinforcement and retrieval induced forgetting at the network level, showing that mnemonic convergence (i.e., memory overlap of members of the communities) was influenced by both the individual level cognitive processes, and by the network structure. This initial work opened a dialogue and raised many questions as research trajectories for future investigations. Future work could expand on testing different types of network structures, assessing the topological and temporal features of these structures that maximize or minimize the propagation of mnemonic influence, assessing sociocultural conditions' impact on the propagation of this influence, etc. Recommending future trajectories in the domain of mnemonic influence is done with the hope that as the body of research addressing these questions will continue to expand, mnemonic influence will be a better understood phenomenon, and its value and potential to benefit society will become more apparent and readily utilizable.

b. The value of mnemonic influence

The malleable nature of memory allows the cognitive system to be subject to mnemonic influence, which has a considerable impact on processes such as emotion, reason, and action. A constant theme stressed throughout this article is the outstanding potential of using mnemonic influence techniques to benefit humanity, in domains ranging from individual (PTSD, addiction) to societal levels (legal system, medical decisions, consumer behaviors), of course, assuming benevolence. These potential benefits are strong arguments for the adaptive function of memory's malleability. Additional arguments in favor of the adaptive view of memory's flexible nature can also be made, for example, by considering how a fixed, rigid, or perfect memory would look like: fictionally emphasized by the Argentine writer Jorge Luis Borges in his 1942 short story "Funes the Memorious" a man with perfect memory, would be incapable of forgetting. Borges depicts this man as incapable to distinguish between trivial and important, prioritize, generalize, or filter information. Thus, Borges concludes in a famous quote "To think is to forget". Scientific research supports the writer's observation and conclusion, after rigorous investigations of real cases of people with near perfect memory, condition called hyperthymesia (Parker, Cahill, McGaugh, 2006). By enabling memory to be malleable, the cognitive system is more flexible, efficient, resourceful, and better prepared to thrive in the complex world it has evolved to navigate. Or in more memorable words, "Memory's mythmaking is necessary for life" (Lejeune, 1991).

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Appendix:

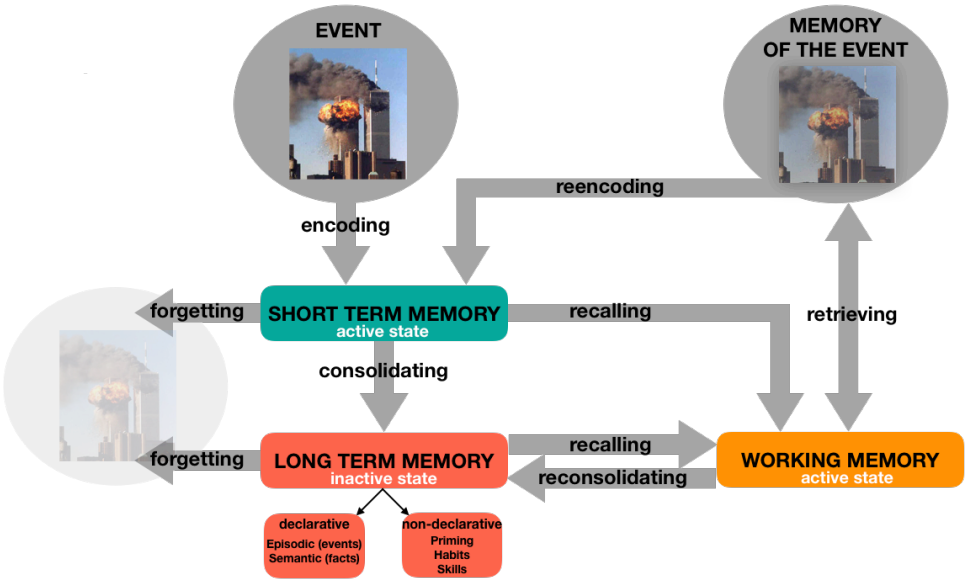

Figure A1. *Memory mechanisms: Consolidation and Reconsolidation*

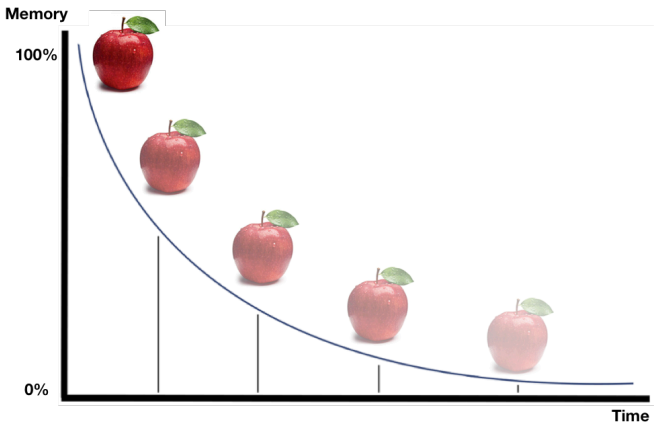

Figure A2. *Memory mechanisms: Decay. Forgetting curve of a memory over time*

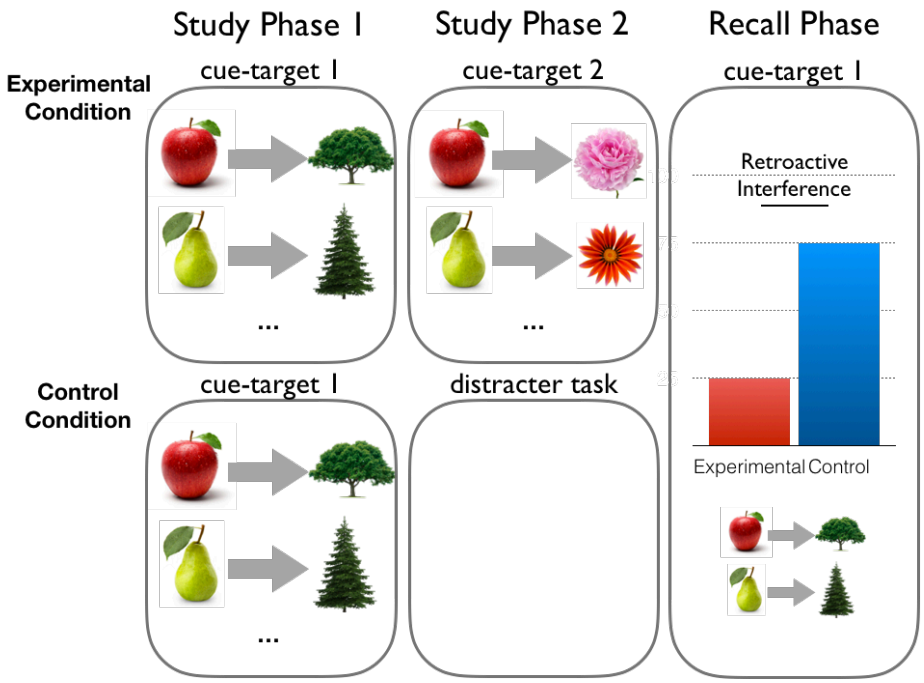

Figure A3a. *Interference standard paradigm: Retroactive interference*

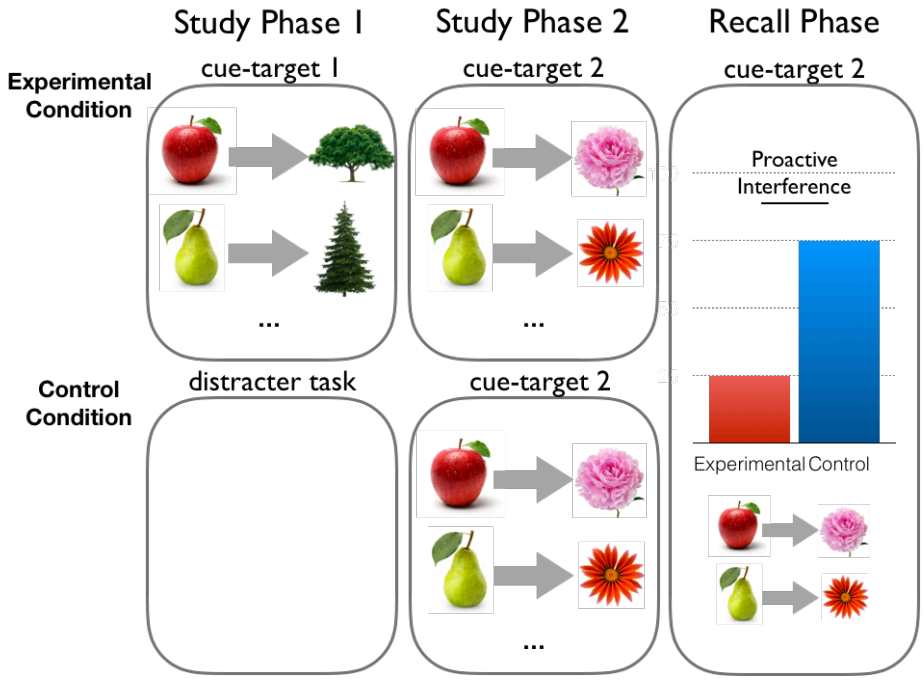

Figure A3b. *Interference standard paradigm: Proactive interference*

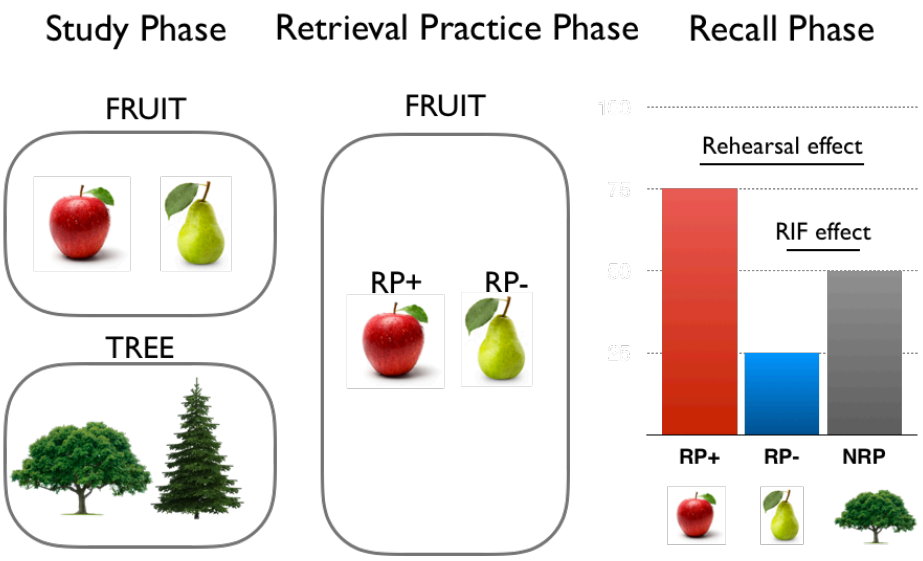

Figure A4. *Selective Practice Paradigm: Rehearsal effect and Retrieval Induced Forgetting effect*

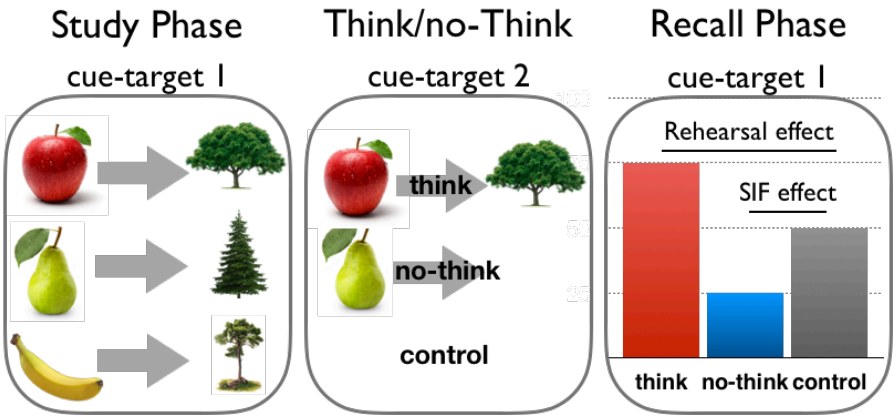

Figure A5a. *Think/no-think paradigm: Suppression induced forgetting*

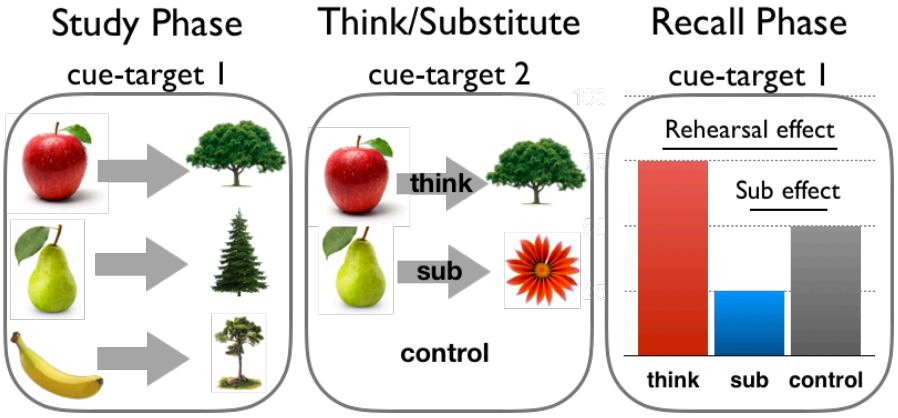

Figure A5b. *Think/no-think paradigm: Thought substitution*