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The Neuroscience of Memory: Implications for the Courtroom

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Abstract

Although memory can be hazy at times, it is often assumed that memories of violent or otherwise stressful events are so well-encoded that they are largely indelible and that confidently retrieved memories are likely to be accurate. However, findings from basic psychological research and neuroscience studies indicate that memory is a reconstructive process that is susceptible to distortion. In the courtroom, even minor memory distortions can have severe consequences that are in part driven by common misunderstandings about memory, e.g. expecting memory to be more veridical than it may actually be.

Introduction

Pioneers in neuroscience such as Ramón y Cajal, Hebb, and Marr introduced the idea that memory is encoded in the patterns of synaptic connectivity between neurons. Increases in the strengths of these synapses encode our experiences and thereby shape our future behavior. Our understanding of the complex mechanisms that underlie learning and memory has progressed dramatically in recent decades, and studies have not provided evidence that memories are indelible. Quite the contrary, it is becoming clear that there are several ways through which memories can change.

The 'imperfection' of memory has been known since the first empirical memory experiments by Ebbinghaus[1], whose famous 'forgetting curve' revealed that people are unable to retrieve roughly 50% of information one hour after encoding. In addition to simple forgetting, memories routinely become distorted[2-7]. The public perception of memory, however, is typically that memory is akin to a video recorder[8] (Box 1). This distinction between the perception and reality of memory has important consequences in the context of the courtroom. In the legal system, like among the general public, it is generally assumed that memory is highly accurate and largely indelible, at least in the case of 'strong' memories.

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Recently, some regional jurisdictions, such as New Jersey[10,11], Massachusetts[12], Texas[13], and North Carolina[14] have implemented procedural changes designed to mitigate effects of memory biases and to best preserve accurate memories of eyewitnesses. However, the legal system writ large has been slow to adapt to research findings on memory, even though these findings have implications not only for eyewitness testimony, but also for how jurors remember and weigh evidence. Interest in the research of memory processes and their relevance to the courtroom has increased since the advent of DNA evidence, which has exonerated hundreds of individuals who were falsely convicted on the basis of eyewitness testimony.

Common misunderstandings about memory

In many countries, the justice system relies on judges and jurors weighing evidence from multiple sources and with varying levels of credibility. The belief that a confident memory is always highly accurate and resistant to distortion or loss is an unfortunate misunderstanding of memory[8] that has important consequences in court. The testimony of eyewitnesses whose memories may have been distorted can lead to the conviction of innocent persons while true perpetrators remain free. The Innocence Project in New York City (www.innocenceproject.org, see Box 2), which advocates the use of DNA testing to exonerate wrongfully convicted people, lists 310 exonerated individuals (as of July 8th, 2013). These individuals were typically convicted on the basis of eyewitness testimony and spent an average of 13.6 years in confinement before being released. They are thought to be only a small sample of the total number of wrongfully convicted people, as DNA evidence is only available in a limited number of cases (e.g., those involving sexual assault).

Most individuals outside the field of memory research (including jurors) are largely unaware of the substantial malleability of memory[2,8,15-17] (however, also see ref. [18]). Early studies on the public awareness of memory phenomena showed that when college students were asked how various factors influence memory (e.g., cross-race identification, stress, and the wording of questions), they were only 54% correct[2]. Although the students scored higher than chance, the score was surprisingly low considering the implications of these factors in court cases. Similar surveys have replicated these findings in nontraditional (older, working) students and in citizens of Washington, D.C. In both of these studies, the respondents' accuracy was below 50%, suggesting that college students may be slightly better informed about factors that influence memory than the general public[15].

More recent studies revealed that judges and law enforcement personnel are not much more aware of memory phenomena than college students[17]. For example, on a 30-item questionnaire about memory-related topics, potential jurors (that is, citizens who have been summoned to jury duty), judges and law enforcement personnel (including detectives, police officers and special agents) responded differently from eyewitness testimony experts on 87%, 60%, and 60% of items respectively[17]. Thus, although judges and law enforcement personnel agreed with memory experts on more statements regarding memory myths than did jurors, their understanding of the majority of memory myths still differed from memory experts. There is evidence that some populations, such as a surveyed sample of Canadian citizens, hold beliefs that are more in line with those of experts[18]. However, the most recent

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studies show that there remains a large discrepancy between public knowledge of memory and expert consensus[8] (Box 1).

One memory phenomenon of which the general public (and therefore also a jury) is often unaware is cross-race bias[17,19] — a reduction in accuracy when identifying faces of a race or ethnic background different from one's own[2,20].

This phenomenon is due to the fact that we use our entire existing body of knowledge and experiences to filter for what we perceive, attend to and use in memory reconstruction (this is known as memory's 'bias'[21]). In the case of facial identification, we are typically most familiar and knowledgable about the facial features of our own race and less so of other races or ethnic backgrounds. Bartlett first drew attention to memory's 'bias' in his famous study on the "War of the Ghosts"[22], in which participants had difficulty recalling short stories word for word when the stories did not fit into their conceptual framework. Barlett's work was later developed by Neisser[23], who famously likened memory retrieval to paleontology by saying "out of a few stored bone chips, we remember a dinosaur". Put simply, if we think an event should have happened in a certain way on the basis of our previous experiences, we are likely to think that the event did indeed happen this way. For example, a study showed that people who read a brief passage about a wild and unruly girl and are told that it is about Helen Keller are more likely to mistakenly remember, a week later, the text saying "she was deaf, dumb, and blind" than if they were told that the passage is about a fictitious Carol Harris[24]. Thus, if people expect certain things to occur during a crime or expect a particular group of people to be more or less involved in crimes, it should perhaps not come as a surprise that their memories reflect these biases.

Another commonly held belief among the general public is that an eyewitness' confidence in the accuracy of his or her memory is a strong indicator of the actual accuracy of the memory[17]. Jurors often place great weight on how confident an eyewitness is regarding their memory of the event — enough to convict an individual even if eyewitness testimony is the only condemning evidence (Box 1). Meta-analyses have reported that mistaken eyewitness identification occurred in 75% or more of cases in which a convicted individual was later exonerated on the basis of DNA evidence[25]. Importantly, memory experts generally do not endorse the idea that the confidence and accuracy of a memory are always tightly linked[8,19]. Although studies in cognitive psychology have shown a positive correlation between memory confidence and accuracy[26,27], these studies were typically laboratory based, used neutral stimuli, and observed general memory phenomena rather than the attributes of memory most relevant to court. Research that specifically examines eyewitness testimony or the memory of traumatic events has shown weak[28] or even negative[6] correlations between a person's confidence in the accuracy of a memory and the actual accuracy of that memory. One reason for these weak correlations is that confidence can be influenced independent of accuracy, for example, by post-identification feedback, which has no influence on accuracy (see below). A decoupling between memory confidence and accuracy in jurors and law enforcement can be seen when college students or law enforcement personnel are given instruction on how to detect behavioral cues of deception. This 'lie detection' training tends to increase confidence in evaluating wether a witness' testimony is truthful or deceitful without necessarily improving the actual accuracy of deception detection[29-31]. The

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relationship between confidence and accuracy is far more complicated than is often acknowledged. Accuracy often produces confidence, but confidence does not necessarily indicate accuracy.

Misunderstandings about memory can have effects on criminal cases even before they make it to court. The belief that confident, detailed memories are always accurate and reliable is contrary to research that suggests the opposite is possible — confidently recalled recollections can sometimes be inaccurate and real memories are not always highly confident and detailed. Especially in cases involving violence and high levels of stress, real traumatic memories — which can be disjointed — may sound unreliable to law enforcement personnel and to the general public and may therefore never make it to court. One striking example of this is that an estimated 86% of sexual assaults are never prosecuted on the grounds that the victim's testimony does not seem to be reliable[32].

How memory distortions occur

Memory distortions can occur in different ways. Most distortions involve some form of explicit or covert misleading information. One form of this phenomenon, the 'misinformation effect', has been thoroughly studied for the last 30 years[4]. This effect refers to a distortion in an original memory after being exposed to misleading information related to that memory, e.g. an impairment in the memory of the face of a perpetrator after being exposed to a photo of a police suspect who was not the true perpetrator. This 'misinformation' is considered misleading in that in distracts from the original memory, not because it is purposefully deceitful. Laboratory studies have shown that it is possible to induce memories in a participant that are entirely false, such as a special hospital visit at age 4 when no such visit happened[4]. Misleading information is often given unintentionally and can be as subtle as slight variations in the wording of a question. For example, when participants viewed footage of a car accident, the question "How fast were the cars going when they *smashed* into each other?" (italics added) elicited reports of 20% greater traveling speeds than the question "How fast were the cars going when they *hit* each other?", despite the fact that participants in both conditions viewed the same footage[2]. The former question was also more likely to elicit a false memory of broken glass at the site of the crash[2]. Witnesses are often called to testify on specific details such as these and their reports may influence the likelihood of conviction and the degree of punishment, i.e. a harsher crime sentence for traveling at higher speeds.

Distortions in memory can also occur from feedback provided to the witness after their testimony. Positive post-identification feedback, such as informing a witness that their choice in a suspect line-up matched the police suspect or was the same as that of other witnesses, increases the eyewitness' level of confidence in their choice[33,34]. Positive post-identification feedback also increases a witness' later estimate of the amount of attention he or she paid to the crime and of how well they could see the scene and/or perpetrator[34,35]. Conversely, negative feedback can deflate confidence in a memory and other measures[33,36]. In addition, nonverbal feedback via body language and facial expressions can occur if the officers conducting the line-up are aware of which individual is the police suspect[37]. Even in the absence of feedback, mere repeated questioning of an event can increase a witness'

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confidence in the accuracy of their memory[38]. Such changes in a witness' reported estimations of confidence and attention are highly relevant in the courtroom, as judges and jurors often use these factors as indications of the accuracy and reliability of a witness's testimony.

Memory distortions can even occur in highly trained individuals. One series of studies examined highly selected military personnel in survival school who received a week of classroom instruction on how to handle stressful interrogations before they were exposed to a mock prisoner of war camp (POWC, see Box 3)[39,40]. The mock POWC provides a controlled setting of realistic and personally relevant stress. In one study of over 500 active-duty military personnel, participants were asked to identify their interrogator after being released from the mock POWC. These individuals had had a clear view of their assailant during the 30-40 minute interrogation. However, only approximately a third of the identifications were correct.

Strikingly, the subjects identified someone in the line-up as the interrogator in almost two thirds of cases in which the actual interrogator was not present in the line-up[39]. A related study involving a population of over 800 military personnel revealed that interrogator identifications were also easily influenced by misinformation. For example, exposure to a misleading photograph of someone who was not the interrogator before identification increased the likelihood of a false identification[40]. The misidentifications that occurred with and without exposure to misinformation were robust, despite the fact that these studies involved a select group of individuals thought to be superior in their ability to handle stressful situations. Although a limitation of these studies is that subject selection may be biased because they involved participants who chose to enroll in survival school, their findings converge with data from laboratory-based studies of eyewitness testimony under highly stressful situations[41,42] and the misinformation effect[4].

Memory distortions can also occur simply with the passage of time and with repeated recounting of events. Although it might not be surprising that mundane memories become weaker and more susceptible to distortion over time, emotional and traumatic 'flashbulb memories' are also susceptible to these automatic distortions. For example, after the September 11th terrorist attacks on New York City, U.S. citizens were asked to remember when they first heard about the attacks. They were asked to recall this episode approximately one to two weeks after 9/11, one year later, and three years later[6]. Memories of the details had changed in 37% of the people after one year and in 43% after three years. Interestingly, despite the drop in memory accuracy, confidence in the accuracy of the memory remained high — an example of a negative relationship between memory confidence and accuracy — and was driven primarily by attention paid to media reports and by talking about the attack in the intervening time[6].

These types of memory distortion increase as we age. For example, false memory for words that were not in a list of words presented to the participant but that were semantically related to the words on the list (a test known as the Deese-Roediger-McDermott (DRM) paradigm) increases with age[3]. Similarly, when shown lists of objects, some of which are similar but not identical to previously seen objects, older participants are more likely than younger

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participants to incorrectly identify these as being repeated objects[43]. By contrast, endorsement rates for repeated items and for novel items unrelated to the listed items are largely unaffected by age. Aging seems to be associated with an over-generalization of memories such that an event that is similar to a prior event is more often remembered as being identical to the prior event. Aged individuals are also more susceptible to the misinformation effect than young adults[4,5]. Thus, as people age, memory for the gist of an event may remain intact, but memory for specific details of the event degrades and individuals are more likely to falsely incorporate similar information into our memories.

The fallibility of memory has implications for the question of how much weight should be given to eyewitness testimony in court cases. In addition, jurors are subject to memory biases. For example, when mock jurors listened to audio recordings of a mock trial, they 'recalled' 15% of details of that were not mentioned in the trial but that fit a typical crime description (e.g., "pulled out a gun" was never stated, but fits the description of a robbery)[9]. This reflects people's natural bias to "fill in the gaps" of a memory, but such fill-ins are inaccurate accounts of the actual events. The occurrence of 'false memories' can be increased by leading questions, such as those that might be asked by prosecutors. Mock jurors 'recalled' 25.8% of details that were implied in leading questions from the prosecuting attorney in a mock trial but that were not stated by the eyewitness of the trial, suggesting that jurors have difficulty in sorting statements from eyewitnesses and attorneys. Moreover, even when mock jurors were given explicit instructions to focus on the testimony of witnesses and not on information implied from attorneys, they still 'recalled' 20.4% of details that were not mentioned in the eyewitness testimony[9]. Thus, such instructions to jurors only marginally reduced the effect of leading questions and did not completely prevent it.

Insights from the neuroscience of memory

Our understanding of the neurobiological mechanisms of memory formation, consolidation and retrieval can explain, at least to some extent, why some types of memory distortions occur and why 'imperfect' memory is the norm. At the cellular and molecular level, these mechanisms are thought to involve processes linked to long-term potentiation (LTP) and long-term depression (LTD).

Long-term potentiation (LTP) and long-term depression (LTD)

Hebb[44] proposed a conceptual framework that linked associative memory formation to activity-dependent changes in the strength of connections in a network, and Bliss and Lømo provided the first direct evidence for such a link[45]. They found that by strongly stimulating the perforant pathway from the entorhinal cortex to the dentate gyrus they had increased the ease with which neurons in the entorhinal cortex could excite neurons in the dentate gyrus . This strengthening of the connections remained quite stable and was dubbed LTP. LTP is activity dependent and requires coincident firing of pairs of neurons. Thus, the learning rule underlying LTP corresponds quite well to the associative learning rule posited by Hebb. There is now substantial evidence that LTP, or at least a similar process that shares many mechanisms with LTP, underlies numerous forms of learning and memory[46].

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A great deal has been learned about LTP, its mechanisms, and its various forms. For example, depolarization without activation of NMDA receptors and protein synthâesis results in an 'early' Hebbian form of LTP that only lasts several hours. By contrast, NMDA receptor-dependent LTP leads to structural changes that show little sign of degradation with time[47]. This could suggest that once a memory undergoes such 'synaptic consolidation' and is associated with the structural changes of late-phase LTP, it is immutable. Unfortunately, this is not the case as these changes are not permanent nor are the memories that have been thus encoded indelible. Although coincident firing of neurons can lead to LTP and the strengthening of a memory, if the neurons fire in an uncorrelated way (as may be the case if the neurons individually activate in different experiences and therefore different memories of those experiences) this leads to the opposite, namely a reduction in the strength of these same synapses that LTP strengthens. Thus, there is a mechanism, known as LTD, for weakening synaptic connections, and therefore presumably memories, as well. Importantly, LTP and LTD occur at the level of individual synapses and the same individual neurons and synapses are likely involved in several or many memories[48], leading to the potential for interference of one memory with another[49] and suggesting that the learning of new information can overwrite previously learned information by changing the strengths of the synapses that had been used to encode that information. Conversely, as noted above, previously learned information (experiences, biases, etc.) can influence the learning of new information.

Moreover, there is evidence on the molecular level that memories can be lost or altered. First, the maintenance of LTP appears to be an active process, as administering zeta-inhibitory peptide (ZIP) can de-potentiate synapses and erase memories[50,51]. Second, the act of retrieving a memory (that is, reactivating a memory) is thought to put that memory and the potentiated synapses in the memory into a labile state, from which it must re-stabilize in order to persist. Without this process, known as 'reconsolidation' (which, like long-lasting LTP, requires protein synthesis), the information is lost[52]. This reconsolidation process is thought to be functionally beneficial as it provides an animal with an opportunity to strengthen or weaken a memory or to update its contents[53]. If the content of a memory is updated at the time of retrieval, memory distortion could occur of which the individual would presumably be entirely unaware[53].

Note that thus far, we have discussed how the contents of an existing memory may be changed. There is reason to believe that more recent memories can compete with older memories at time of retrieval, leading to memory errors when trying to retrieve the original information [54]. That is, if two different memories exist of an event (e.g., the original memory and a memory formed while retelling the event) or if there are two overlapping memories (e.g., the original memory of the event in question and memories of a subsequent event that shares several of the same components), attempting to retrieve the original event may very well inadvertently and unknowingly draw upon information from the second event. There are neurobiological findings that support this mechanism for altering memory performance. For example, the extinction of a conditioned response engages many (though perhaps not all) of the same mechanisms that were engaged during the initial learning of the response[55], supporting the notion that extinction is not simply the loss of an existing association but involves new learning. The phenomena of spontaneous recovery

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(reappearance of a previously extinguished memory) (reference) and disinhibition (re-emergence of a conditioned response after experiencing a novel stimulus) (reference) also support this notion.

Generalization over time and with retrieval

Memory distortions in humans may occur simply with the passage of time. This is partly because over time memories typically become less episodic (highly detailed and specific) and more semantic (more broad and generalized) as the information is repeatedly retrieved and re-encoded in varying contexts. This generalization of a memory over time has also been observed in animals. For example, if a rodent receives an electric footshock in a particular context, subsequent exposures to that context induce a 'freezing' behavior[56]. The specificity of the memory can be probed by exposing the animal to a different context. Comparing the levels of freezing in the two contexts reveals how well the animal discriminates between them (Figure 1). A typical finding is that freezing in the training environment may not degrade much with delay (i.e. the animal shows little forgetting of the memory) and that the level of freezing in the alternate context is initially very low. However, freezing in the alternate context typically increases with delay, indicating a reduction in the ability to discriminate between the contexts in memory or an increased reliance on the 'gist' of a context than on specific contextual details[57,58]. Thus, even highly salient, strong memories, such as the memory of receiving a shock, that are initially detailed and specific but become more generalized with the passage of time. Such generalization is stronger for similar contexts than for highly dissimilar ones, and the hippocampus is required to differentiate between contexts as it maintains the representations of the details that distinguish them[59].

During the formation of a new episodic memory, information about a related memory can be automatically retrieved. New learning taking place to encode this new episode can spill over and alter the contents of this automatically retrieved information. For example, in one study[60] rats were exposed to two distinct contexts (A and B) on the same day over the course of several days, so that some association would probably be formed between the two contexts (A–B). The rats were then exposed to one of the contexts (B). Given the prior training, rats quite likely retrieved a memory of the other context (A). At this point, rats were given a shock. Subsequently, the level of freezing the animals showed in context A was higher than that in a novel context (C)[60]. This finding is consistent with the idea that being placed in the B context reactivated the memory of context A, so that the association between context B and shock 'spilled over' to form a false association between context A and shock. Just like the learning of accurate associations, the learning of this inaccurate retrieval-mediated association relies upon NMDA receptors in the hippocampus[61].

Thus, experiencing an event can lead to the automatic retrieval of information that is not present but has been previously associated with similar events. Given that a goal of our memory system should be the use of prior information to guide current behavior in an adaptive manner, such automatic retrieval of memories from related events would be expected. However, a problem arises with the notion that learning is occurring at this point and that it does not clearly discriminate between the current event and retrieved information

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from specific prior events or from generalized expectations of what should happen in such an event. As a result, whatever happens in this event becomes associated not just to elements that are actually present, but also to what we expect to be present based on our prior experiences and biases. This phenomenon was shown in an elegant neuroimaging study in humans[62]. Here, participants initially encoded a series of image pairs (A–B). After a test on the memory for these pairs, they again encoded a series of image pairs. Some of these pairs repeated an element from the initial encoding list (A–C). During this second encoding phase, there was evidence for the reactivation of previous, related events (A–B) in activity of the hippocampus. The amount of activity for the original A–B event during this related A– C retrieval predicted how much of the original A–B information was lost and how much of the novel A-C information was retained[62].

It is important to note that even without considering the notion of deception, it is difficult to distinguish true memories from false memories by examining brain activity. The relative amount of hippocampal activity during the encoding of an event and during subsequent encoding of misinformation predicts which version will be remembered, even when participants are confident in the accuracy of their false memory[63]. Thus, the formation of 'true' and 'false' memories appears to involve the same processes. At time of retrieval, differences in activity in early sensory regions for true and false memories can be observed[64,65], consistent with findings that true memories contain greater sensory detail than false memories[3,66]. Some regions in the prefrontal cortex may be more active during the formation and/or retrieval of false than true memories[67]. However, these differences in activation cannot discriminate true from false on a trial by trial basis (reference - it's that same Ref 67). . This is important in the context of eyewitness testimony, as the time elapsed between witnessing an event and testifying about it in court may render these signals useless for distinguishing true and false memories via brain activity. Lastly, most differences in brain activity are observed in early sensory regions of the cortex, which are not typically associated with conscious awareness, suggesting that we may not be able to consciously know the truth even if some regions of our brains could differentiate true from false.

The closest that experimenters have come in being able to distinguish 'true' from 'false' memories on a trial by trial basis is with the use of multi-voxel pattern analysis (MVPA), a relatively novel method of analyzing fMRI data using pattern classifiers that learn to use stimulus-related activity across voxels to categorize stimuli. MVPA can distinguish *subjectively* remembered from forgotten images with ~70-75% accuracy[68]. However, MVPA classifiers performed either at chance or only marginally above chance when trying to distinguish *objectively* true from false memories — far below their accuracy for subjective memory[68]. Thus, even the most cutting edge neuroimaging techniques are currently unable to distinguish objectively true and false memories from analyzing brain activity.

Stress and memory

It is well-established that arousal and the stress hormones epinephrine and cortisol that are released during arousal can modulate synaptic consolidation and memory strength[69]. Decades of research have supported the view that emotional arousal leads to activation of

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the basolateral amygdala (BLA), which modulates memory storage, leading to more strongly encoded memories. This does not imply, however, that memories encoded during a state of heightened arousal cannot be lost or distorted. In fact, high levels of stress during an event are not necessarily associated with an increase in memory strength for that event and can even result in a reduced memory for the event. Indeed, in both animals and humans there is an inverted-U shaped dose– response relationship between plasma stress hormone levels and memory performance[69,70]. Very high levels of stress during an event are not necessarily associated with an increase in memory strength for that event and can even result in a reduced memory for the event. For example, high levels of either endogenous or exogenous cortisol in humans can impair declarative memory formation[71]. Thus, in high states of arousal, such as witnessing a crime or being a victim of crime, memory encoding may be enhanced or impaired depending on the person's individual stress response.

Emotional arousal has effects during retrieval as well. The retrieval of arousing information leads to a reactivation of the BLA, which can lead to further strengthening of memory[72]. However, distortions can occur if any aspect of the retrieval or reconstruction of the memory is erroneous. As the retrieved information is re-encoded, these distortions (be they self-generated or externally suggested) can potentially become part of the memory. In addition, in humans, high levels of the stress hormone cortisol during retrieval (induced either exogenously[73] or endogenously[74]) have been shown to impair the retrieval of personal autobiographical memory retrieval. Importantly, arousal may enhance memory for some aspects of an event and impair memory for other aspects. For example, violence and trauma tend to improve memory for the central gist of an event (e.g. witnessing a homicide), but impair memory of the peripheral details of the event (e.g. the clothing of the perpetrator)[41,42].

Clearly, the relationship between stress and memory is complicated. Veridical memories may not always be accompanied by a high level of confidence and details. In particular, victims of violent or otherwise upsetting crimes may have vague and disjointed memories of the event, especially during a first interview soon after the crime, when stress levels are still high. It should not be surprising if a second interview, conducted when the stress hormones have returned closer to baseline levels, contains a more coherent story, with additional details that were not recalled on the first interview. Even without stress, memory retrieval is a probabilistic process. This was first shown by Ebbinghaus for retrieval of simple, neutral lists of syllables[1]. As stress is added into the process, the picture is clouded even more. The animal data discussed above suggest that the stress of witnessing a crime or the stress of the first interview can either enhance or impair the encoding and retrieval of the crime event. Stress will also therefore affect the likelihood of establishing false memories during a second interview. Laboratory studies have shown that over time false memories are more likely to be endorsed as real memories and these false memories tend to include more peripheral details with time[75-77]. Thus, there is no set rule that information retrieved across multiple interviews is inherently true or false. A broader understanding of memory processes (the effects of emotion and time), situational factors (how stressful was the experience to the witness), and testimony consistency (what information was consistent or incongruent across interviews) must be taken into account when considering information provided by eyewitnesses.

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Application to courts

The data reviewed above show that memory is imperfect, and that we cannot assume that this is well-understood by the general public and by the courts. Relatively simple changes in procedures can help to reduce the occurrence of memory distortions.. Even in situations where the possibility of memory distortions cannot be avoided, judges and jurors can be better educated on the limitations of memory. The fact that memory is imperfect cannot be changed, Perhaps we can change how much weight is placed on evidence drawn from memory and on the confidence ascribed to memory.

Most of the time, peripheral details of events are of low importance and are therefore often not well recalled. However, in the courtroom, witnesses are often called to testify on precisely such very specific details. Some witnesses may give accounts that are missing details, hazy in places, and may even have some amount of demonstrable distortion. They may report to be unconfident in much of the memory as well. Other witnesses with the same actual amount of information available for retrieval may present far clearer, more detailed accounts with strong confidence given to their memory. As described above, the extra information presented and the confidence in the recall would be driven in these witnesses by the reconstructive nature of memory retrieval. Thus, although in general, accurate memories are more confidently recalled and detailed than inaccurate memories, jurors should be aware that sometimes vague, somewhat distorted memories may be more veridical than very detailed and confident accounts. Given what we know about the neurobiology of memory and the cognitive psychological research on memory, "perfect" memories that are accompanied by a high level of confidence and detail should be taken with a grain of salt and "imperfect" memories that are vague and missing details should not be immediately discredited. However 'good' a witness' memory of an event may be, the witness' memory may not actually be accurate, and currently there is no clear way to tell. This does not mean that memory-based evidence should be thrown out, but rather that police, judges and jurors should be educated on these nuances so that they may give memory-based evidence its proper weight.

Interviewing eyewitnesses

Although the relationship between confidence in the accuracy of a memory and the actual accuracy of a memory is complex, confidence statements should be recorded immediately after an interview or suspect identification[25] before the witness' subjective feeling of confidence can be influenced by post-identification feedback[33-36] or other factors[37,38]. If confidence is to be used as an indication of memory accuracy, this would be the best estimate of confidence to use.

There is a large literature on different approaches to interviewing eyewitnesses. The cognitive interview (CI), sometimes referred to as the 'enhanced' cognitive interview, was developed by psychologists in response to a request from law enforcement for better interviewing methods[25,78]. Here we will review the general outline of the CI as it lays a solid foundation of best practices.

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Interviewing should begin with a transfer of control to the witness, i.e. witnesses should be put at ease and made to feel comfortable. This is important in avoiding unintentional bias as witnesses may be easily manipulated by individuals of perceived power and authority, such as law enforcement. It is recommended that officers request the witness to mentally recreate the scene of the crime. This is based on research on context-dependent memory, which has shown that recall is better when it occurs in the same context as learning[79].

Testimony ought to begin with an open-ended narrative; that is, witnesses should be encouraged to recall as much detail as possible, even if they recall events out of order or the details seem trivial. The interviewer should allow time for long pauses while the eyewitness thinks, relaxes, and gathers his or her thoughts. This approach contrasts with standard police interviews, in which a witness may often be interrupted and asked to report events in a specific order. Allowing witnesses to report events in their own order and at their own pace results in a more detailed and more accurate report[25]. Witnesses should be asked to indicate when they are unsure and should be informed that they should not guess.

After the free narrative, the interviewer can follow up with open-ended questions, keeping in mind that the wording of a question can lead to memory distortions (as discussed above). Indefinite articles should be used over definite articles. For example, asking whether the witness saw 'the gun' as opposed to 'a gun' implies that a gun was present[2]. Lastly, it should be kept in mind that congruency among multiple eyewitness accounts does not necessarily entail greater accuracy as witnesses may communicate with each other and all are susceptible to the same memory errors.

Identification of suspects

There are many guidelines for constructing and conducting suspect line-ups. These guidelines suggest that each line-up should only contain one suspect and the suspect should not stand out from the rest of the line-up. Fillers (other non-suspects in the line-up) should be selected on the basis of the eyewitness' description of the perpetrator. If an innocent suspect fits the description of the perpetrator more than the other people in the lineup, there is a higher likelihood that the suspect will be misidentified as the perpetrator. In a truly unbiased line-up, naive 'mock witnesses' who did not witness the crime should not select any one individual more frequently than the others[2,25].

Although no line-up method can completely eliminate false identifications and increase the likelihood of a correct identification, some recommendations will reduce the number of misidentifications without substantially reducing the likelihood of a correct identification. The first is to warn witnesses that the true perpetrator may not be present in the line-up. Research has found that experimental witnesses have a tendency to select a suspect even if the actual target is not in the line-up[39,40]. The instruction that the suspect may not be present in the line-up has substantially reduced the number of misidentifications, especially in line-ups in which the target was absent. Although the number of correct identifications were also reduced in these studies, this was only to a small degree[25,80]. Secondly, sequential line-ups (in which the potential suspects are shown one after the other) tend to produce fewer false identifications than simultaneous line-ups (in which all potential suspects are shown together) (see Box 3). This approach also reduces the number of correct identifications, but

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typically to only to a small degree[81,82]. The adoption of these procedures has met resistance, which generally is based on the fear that it may lead to fewer convictions of guilty suspects[83]. Although these procedures may indeed increase the number of type I errors (no identification of guilty suspects, and therefore fewer convictions), they reduce the number of type II errors (wrongful identification of innocent suspects, and therefore wrongful convictions) without a cost to overall accuracy; i.e., they lead to a shift towards more conservative identification, which favours protecting innocent suspects.

As previously discussed, distortions in memory can occur as a result of post-identification feedback, whether intentional or not[33-36]. Double-blind line-ups, in which the official who administers the line-up does not know who the police suspect is, would reduce such unintentional bias[25]. One critique against using double-blind line-ups has been the cost of and need for extra manpower to administer these line-ups. However, computer programs can be used to administer the line-ups in a blind fashion by showing photos of suspects on a computer screen without any police officers being present, thereby alleviating this concern.

Recommendations for judges and jurors

It is important to remember that the courtroom also places large demands on the memory of judges and jurors. Jurors are often faced with complex legal instructions and procedures. Simple, clear written instructions from judges help to clarify the deliberation process. In particular, given the data described above concerning misinformation[2,4], jurors should be warned of the effects of misleading questions by attorneys. Jurors are subjected to prosecutors and defence attorneys who may deliberately try to confuse them, redirect their attention, and play to their emotions. There are opportunities for retroactive and proactive interference as lawyers interject arguments during the court proceedings. In particular, misleading questions may imply that facts were presented in evidence by a witness which were not actually presented. Although such education does not eliminate the tendency to incorporate information based on biases, it does reduce its effects[9].

Jurors should likewise be instructed that the memory of an eyewitness should not be considered to be indelible, even if the event was traumatic[39-42]; that a person's biases and expectations will change with time and new information (or misinformation[4,40]), and that this can alter the memory; that a witness' confidence that their memory is accurate is no guarantee that the memory is indeed accurate[6,28,31,34-36]; and that even what is encoded in the first place is filtered by a person's preconceived notions and schemas[84], and people have a tendency to 'fill in the gaps' in a memory[9]. An understanding of these issues may help jurors to realize that eyewitness testimony is not equivalent to DNA evidence in probative value. Some regional jurisdictions, such as New Jersey[10,11], Massachusetts[12], Texas[13], and North Carolina[14] have begun to provide instructions to jurors on how to approach eyewitness testimony[10,12-14].

Additionally, it is recommended that jurors be allowed to take notes as the sheer amount of information presented to jurors often exceeds reasonable demands on memory capacity. As jurors are eyewitnesses to the events in the courtroom, their memories of these events may also be vague and may be reconstructed based on biases, prior beliefs and expectations, and misinformation. Courtroom transcripts may be available, but they are often not useful

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because jurors have difficulty finding the pertinent information in the lengthy transcripts. Taking notes not only provides a source of reference, but improves the memory itself (reference). Although some might argue that a juror who takes notes might dominate deliberations, encouraging all jurors to take notes could overcome this problem. Like eyewitnesses, a juror espousing great confidence in his or her recollection is more likely to be trusted. It would be beneficial to at least have this trust based on notes rather than on memory alone.

Conclusions

Memory is imperfect and is susceptible to distortion and loss. There are adaptive reasons for generalization and forgetting[7]. Indeed, Luria's famous report of the mnemonist S.[85] readily shows how an inability to forget can severely impair normal functioning. In addition, the neurobiological mechanisms that underlie the occurrence of distortions in memory also allow memories to be updated and strengthened. Unfortunately, in the courtroom 'memory' is often misunderstood and undue assumptions are made about its veridicality.

Thus, there needs to be greater education and awareness of memory processes in judicial settings and in daily life. Society would benefit from a better understanding of what factors affect memory accuracy and of their complexity and potentially counter-intuitive nature. Secondly, the legal system needs to reevaluate the probative value of memory. Witnessing a potentially traumatic event does not produce an unbiased, indelible memory of the event. Memory is an adaptive process based on reconstruction. It works well for what it is intended — guiding current and future behaviour. However, it is not infallible, and therefore should not be treated as such. For these reasons, some have argued that the legal system should not convict individuals on eyewitness testimony alone, but rather should require corroborative evidence[83,86]. Lastly, more research ought to be carried out on the complex mechanisms that underlie memory so that we can better understand its limits, improve its reliability, and detect when it has gone awry.

Glossary

"War of the Ghosts"	a Native American fable used by Barlett which was difficult for English participants to recall precisely because it did not fit into their conceptual framework, i.e. English participants were not familiar with Native American traditions and therefore they tended to reinterpret the story in a context more inline with English culture.
Lie detection training	classroom instruction given to law enforcement personnel on how to detect subtle cues of deception.
Misinformation effect	a distortion in an original memory or creation of a false memory after being exposed to misleading information related to the memory. The 'misinformation' is considered 'misleading' in that in distracts from the true memory, not because it is purposefully deceitful.

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Weapon focus the tendency for a witness' attention to be drawn to a weapon, thereby increasing subsequent memory for the weapon, but impairing memory for the perpetrator.

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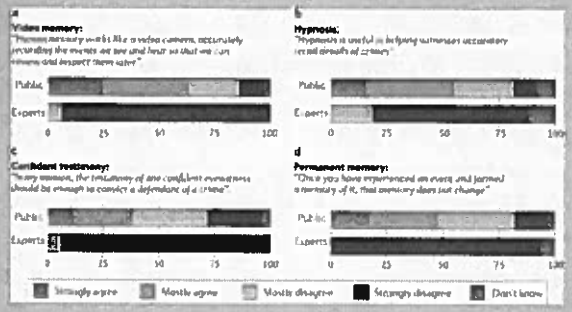
Box 1. Is memory common sense? Public opinion versus memory experts



When asked about statements about memory-related phenomena in a national survey across the United States, members of the general public (n = 1500) accepted many phenomena that were not endorsed by experts in the field (i.e., professors with more than 10 years of experience in memory research), who showed strong consensus among themselves (see the figure) [8]. Such misunderstandings of memory can have significant consequences in court, where judges and jurors often assume memory to be more accurate and veridical than is indicated by the neurobiologically reconstructive nature of memory. Note that one limitation of these surveys is that expert opinion about memory-related phenomena may change over time as more research findings become available. For example, a 1989 study[16] showed that expert opinion regarding the phenomenon of "weapon focus" had changed compared to a survey published in 1982[15] and further changes in expert opinion regarding "weapon focus" as well as other phenomena were shown in 2001[19]. Although expert opinion about memory-related phenomena may sometimes be wrong, it is presumably the best indication of the true nature of such phenomena. The authors of one recent study[18] suggested that public and expert opinion are beginning to converge. However, other studies suggest that in some aspects lay beliefs are still quite different from those of experts. There is, therefore, a need for periodic updating of both expert and public opinion. Data from Ref. [8].

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Box 2. The Innocence Project

In 1981, Linda Mae Craig, a young sales associate, was abducted from her car on her way home from work. The next day, her body was found in a church parking lot beaten and sexually assaulted. Days later, 20 year old Nicholas Yarris was stopped for a routine traffic violation, which escalated into a physical altercation and resulted in Yarris being taken into custody. In a bid to speed his release from custody, Yarris told police he believed an acquaintance was involved in the murder. However, when the acquaintance's alibi was cleared, Yarris became the chief suspect. After a short trial, which involved eyewitness testimony of the victim's coworkers, Yarris was sentenced to death row and solitary confinement for the kidnapping, rape, and murder of Craig. Yarris spent over 21 years behind bars before he was exonerated via DNA testing. He was the 13th individual in the United States to be exonerated from death row.

Yarris' story is one of hundreds recorded by the Innocence Project (www.innocenceproject.org), a nonprofit ligation organization in the United States. According to their data, exonerees spend an average of 13.6 years in prison before being released. After exoneration, there is little support or assistance. The average compensation, which is not guaranteed, amounts to $24,000 a year for each year spent behind bars, often capping at a maximum of 10 years. This does not take into consideration money exonerees have spent on legal fees. Not only have they lost precious and prime years of their life, many exonerees are never acknowledged as victims of legal injustice. They find it difficult to regain a normal life after release from prison. Many have lost friends and family over the years in confinement and bear the social stigma of a criminal, which leads to difficulties finding employment, even after their record is cleared.

Eyewitness testimony plays a role in roughly 75% of all cases in which individuals are wrongfully convicted[25]. The Innocence Project aims to reform the criminal justice system by raising awareness on these issues and advocating for changes in public policy.

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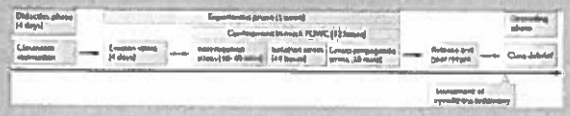
Box 3. Mock Prisoner Of War Camp (POWC) studies on eyewitness identification



Although eyewitness testimony has been empirically studies for decades, the majority of research involved videotaped scenes or live simulations of crimes. A critique of such laboratory experiments is that they lack personally relevant and realistic stress. A few studies did involve actual crimes[87,88,28], but these studies suffered from a lack of control over the amount and duration of stress as well as objective data on the true perpetrator. The mock Prisoner Of War Camp (POWC) portion of military survival school, which enlists only the most highly trained military personnel, provides an ideal venue to study eyewitness identification in a highly realistic and yet controlled setting. High levels of personally relevant stress can be applied in a uniform and consistent manner to all participants. The levels of stress induced in mock-POWC participants have noticeable physiological and psychological effects[89] on par with real-world threats such as combat.

Survival school begins with a week of training to prepare students for the mock POWC, including training to withstand intense interrogation and to resist counter-cultural propaganda. During the mock POWC, each participant is placed in isolation, deprived of food and uniform sleep for approximately 48 hours and is interrogated in a manner that threatens physical violence (e.g. slapping, punching, submission positions[40]). Interrogations last 30-40 minutes and participants have a clear view of their interrogator the entire time. The participants were asked to identify their interrogator approximately 24 hours after being released from the mock POWC and after being given access to food and sleep (see the figure). In some cases, they were given misinformation before making identifications.

One mock POWC study with over 500 survival camp attendees implemented three different types of line-ups[39]: live, in-person line-ups; simultaneous photo line-ups, in which photos of possible interrogators are shown at the same time and witnesses must select the interrogator (if present) in the photo spread; and sequential photo line-ups, in which photos of possible interrogators are shown one at a time and witnesses must decide for each of them whether they were the perpetrator. Participants correctly identified their interrogator in ~33% of cases in which the interrogator was present in the line-up. When the interrogator was not present in the line-up, participants made false-positive identifications (that is, they identified an 'innocent' person as the interrogator) in almost 66% of cases. These mock POWC results support previous findings that sequential line-ups elicit fewer misidentifications than simultaneous line-ups[83]. Another POWC study involving a separate population of over 800 military personnel[40] has replicated findings of the misinformation effect[4]: exposure to misleading photographs or leading questions increased the likelihood of false identifications or inaccurate memories.

The participants of survival school are successful military personnel who are often selected for their perceived ability to handle high-stress situations. Strikingly, these

mock-POWC studies show that even such highly trained individuals are susceptible to memory distortions, to making false identifications, and are

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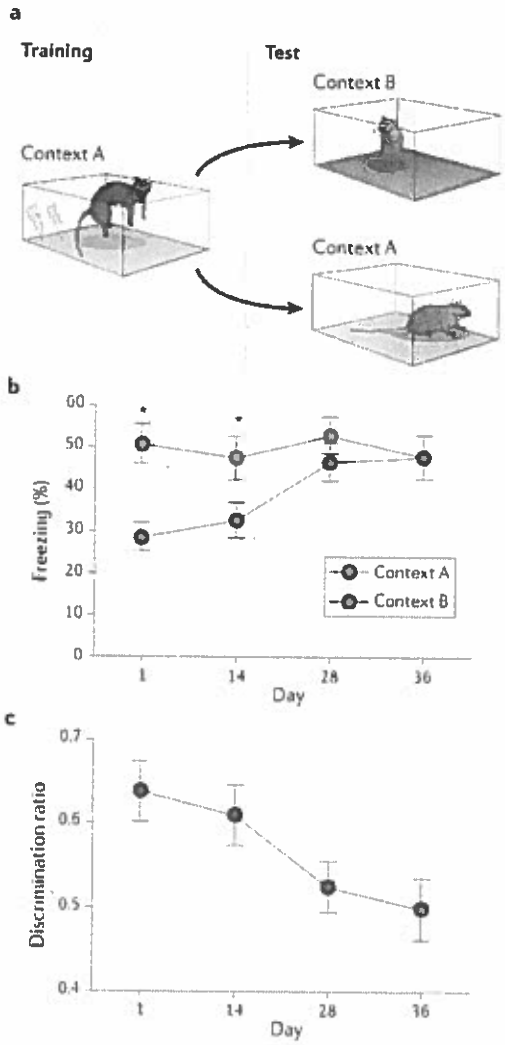

Figure 1. Memory generalization over time in rodents

Rats were exposed to a training context (context A) and given a small shock in that context, which induces a "freezing" behaviour (a common fear response in rodents). After a delay, they were placed in either the training context (context A) or a novel context (context B). Memory for the shock and the specific environment it was given in can be assessed by measuring the amount of time the rats spend "freezing" in each context. One day after training, rats froze less in the novel context than they did when re-exposed to the training context. This behavior displays memory of the specific context in which they were shocked, and this ability to discriminate between the two context decreases with time. Rats that were tested 4 weeks after training froze an equal amount of time in the training context and the novel context. This suggests that both the training and test contexts (both of which involve the rat being removed from the home cage, taken to another room, placed in a box, etc.) match the contents of the memory. Figure adapted from ref [59].