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Review article

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Active intentional and unintentional forgetting in the laboratory and everyday life

Jonathan M. Fawcett[1], Tracy L. Taylor[2], Emma Megla[3] & Ashleigh M. Maxcey[4]

Abstract

Forgetting can result from passive or active processes. Active forgetting includes purposefully trying to forget or retrieve competing information. Knowledge about active forgetting in humans is largely derived from controlled laboratory experiments, but similar forgetting occurs in everyday settings. In this Review, we discuss two major categories of active forgetting: one in which a person aims to forget (intentional forgetting), and the other in which a person does not (unintentional forgetting). In the laboratory, intentional forgetting occurs when a person forgets information after being directed to do so. Outside the laboratory, intentional forgetting occurs when unwanted information is forgotten volitionally, such as an incorrectly stated phone number or an upsetting experience. Unintentional forgetting in the laboratory occurs when retrieving information from memory actively induces the forgetting of related information. Unintentional forgetting outside the laboratory can also be trivial, such as which pumpkin your child selected at the pumpkin patch, or consequential, such as forgetting which jacket was worn by a perpetrator when witnessing a crime. We review efforts to map laboratory results onto everyday forgetting and make recommendations for future research, addressing everyday forgetting as well as clinical applications.

Sections

[1]Department of Psychology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada. [2]Department of Psychology and Neuroscience, Dalhousie University, Halifax, Nova Scotia, Canada. [3]Department of Psychology, University of Chicago, Chicago, IL, USA. [4]Department of Psychology, Vanderbilt University, Nashville, TN, USA. e-mail: jmfawcet@gmail.com; ammaxcey@gmail.com

Introduction

The benefits of forgetting are easy to overlook. When someone forgets something that they wish to remember, the absence of that information is disruptive and often caused by processes that give the impression that the memory has simply faded with the passage of time. However, when someone purposefully forgets something that is aversive or of no further use, this useful act is invisible – akin to creating negative space that enables more important things to enter the foreground[1–3]. To understand the importance of forgetting, one need only consider case studies of people who are unable to do so. For example, individuals suffering from hyperthymesia demonstrate a limited ability to forget even the most mundane details of life[4,5]. Although it might seem a neat parlour trick to rattle off news headlines by publication date or the plots of TV shows by episode, this condition leaves some individuals debilitated by the sting of every negative memory, making it nearly impossible to 'forgive and forget'. Therefore, although forgetting is undoubtedly inconvenient at times, it can also be a gift.

Forgetting can be distinguished according to intentionality – whether the forgetting is accomplished purposefully or whether it is an unintentional side-effect of other kinds of memory processes. In daily life, the most apparent instances of forgetting are unintentional failures to remember – those frustrating moments in which you cannot remember where you placed your keys or the name of an acquaintance. This kind of unintentional forgetting contrasts with goal-directed intentional forgetting, which is done on purpose. Intentional forgetting can occur at encoding or at retrieval. Forgetting at encoding prevents information from being committed to long-term memory, ensuring that the unwanted information is not available for later retrieval. By contrast, forgetting at retrieval means that the information is present in long-term memory but not accessible.

There are many different types of memory[6,7]. Intentional and unintentional forgetting are typically studied for episodic memories. Episodic memories are situated in a time or place, allowing them to be retrieved, for example, by thinking about a specific event or experience, such as the last time that one visited the ocean. Researchers are often interested in understanding when, whether and how participants forget information that was presented during a particular learning episode, such as during the study trials of an experiment. Episodic memory might be tested in a recall task that asks participants to think about a studied list and report all the words they remember, or in a recognition task that requires them to decide whether or not a presented item was on that studied list. These approaches to testing memory differ in that recall usually involves generating the desired information from memory, cued by a reminder (such as 'Recall the words you just studied'), whereas recognition involves viewing something that might have been studied and deciding whether it is present in memory.

Intentional and unintentional forgetting of episodic memories are usually studied in the laboratory but also occur outside the laboratory in everyday settings. Such settings are those likely to be encountered in daily life, as opposed to only in a laboratory setting. That said, the distinction is not always clear, because even in laboratory studies, there is variation in how similar the memory task is to real life. For instance, trying to forget that one has seen a word or picture might seem less 'everyday' than trying to forget a personal experience from one's past. And there are other times when everyday life approximates a laboratory task, such as mentally rehearsing items in a grocery list on the way to the shop. Moreover, in everyday life, the desire to intentionally forget might range from a matter of convenience, such as choosing to forget a newly created password that was rejected by a website, to the dire need to overcome intrusive memories of trauma. Likewise, everyday examples of unintentional forgetting range from low-risk forgetting of grocery list items to hazardous forgetting of eyewitness details.

In this Review, we leverage our traditionally siloed expertise in intentional and unintentional forgetting to understand the ways in which active processes contribute to forgetting of episodic memories, and we explore how forgetting manifests in everyday settings. We first review intentional forgetting through the lens of the directed forgetting paradigm[8] and the think/no-think paradigm[9] and consider the potential underlying mechanisms of forgetting in these tasks[1,10–13]. We then consider how intentional forgetting might be experienced in everyday life outside the laboratory, drawing on laboratory results to contextualize and understand these experiences. Next, we review unintentional forgetting studied in the laboratory using the retrieval-induced forgetting paradigm[14] and the recognition-induced forgetting paradigm[15], and then explore everyday unintentional forgetting. Finally, we examine intentional and unintentional forgetting across these two settings before considering future directions that integrate both fields.

Laboratory-based intentional forgetting

In the laboratory, intentional forgetting is usually studied using three paradigms: list-method directed forgetting, item-method directed forgetting and think/no-think (Fig. 1). Each of these paradigms taps into different, but overlapping, cognitive control processes[16,17].

In list-method directed forgetting (Fig. 1a), participants are presented with a list of items that they are asked to commit to memory. Midway through the list, half of the participants receive a surprise instruction to forget the first half of the list – sometimes under the ruse of a computer error that caused the wrong list to be presented – and are asked to remember only the second half of the list. The other half of the participants are likewise interrupted mid-list but their instruction is to carry on remembering the first half of the list and to also remember the second half of the list. Compared to participants who receive the mid-list 'remember' instruction, those who receive a mid-list 'forget' instruction show poorer recall for the first half of the list, but better recall for the second half of the list. In other words, an instruction to forget the first half of the list costs these items but benefits the items that come afterwards in the second half of the list. Taken together, the costs and benefits are referred to as the list-method directed forgetting effect[8].

The list-method directed forgetting effect is robust for recall[10,18] and can also occur for recognition under certain circumstances (such as for nonword letter strings)[19,20]. As to the mechanisms underlying this effect, early theorists postulated that an instruction to forget prompts list-wide inhibition, tamping down the items in the first half of the list so that, despite having been encoded into long-term memory, they become relatively inaccessible for retrieval[1,10,11]. In the list-method directed forgetting paradigm, presenting the inhibited items from the first half of the list again during a recognition test was thought to trigger a release from inhibition and eliminate the effects of directed forgetting[10] – explaining why the list-method directed forgetting effect is more robust for recall than for recognition. An alternative conceptualization suggests that the instruction to forget provokes a change in mental set that establishes a different context for encoding the second half of the list, compared to the first half of the list[12,13]. Context can include characteristics of the physical environment, such as the room in which the experience occurred, as well as mood or internal mental states experienced during encoding and

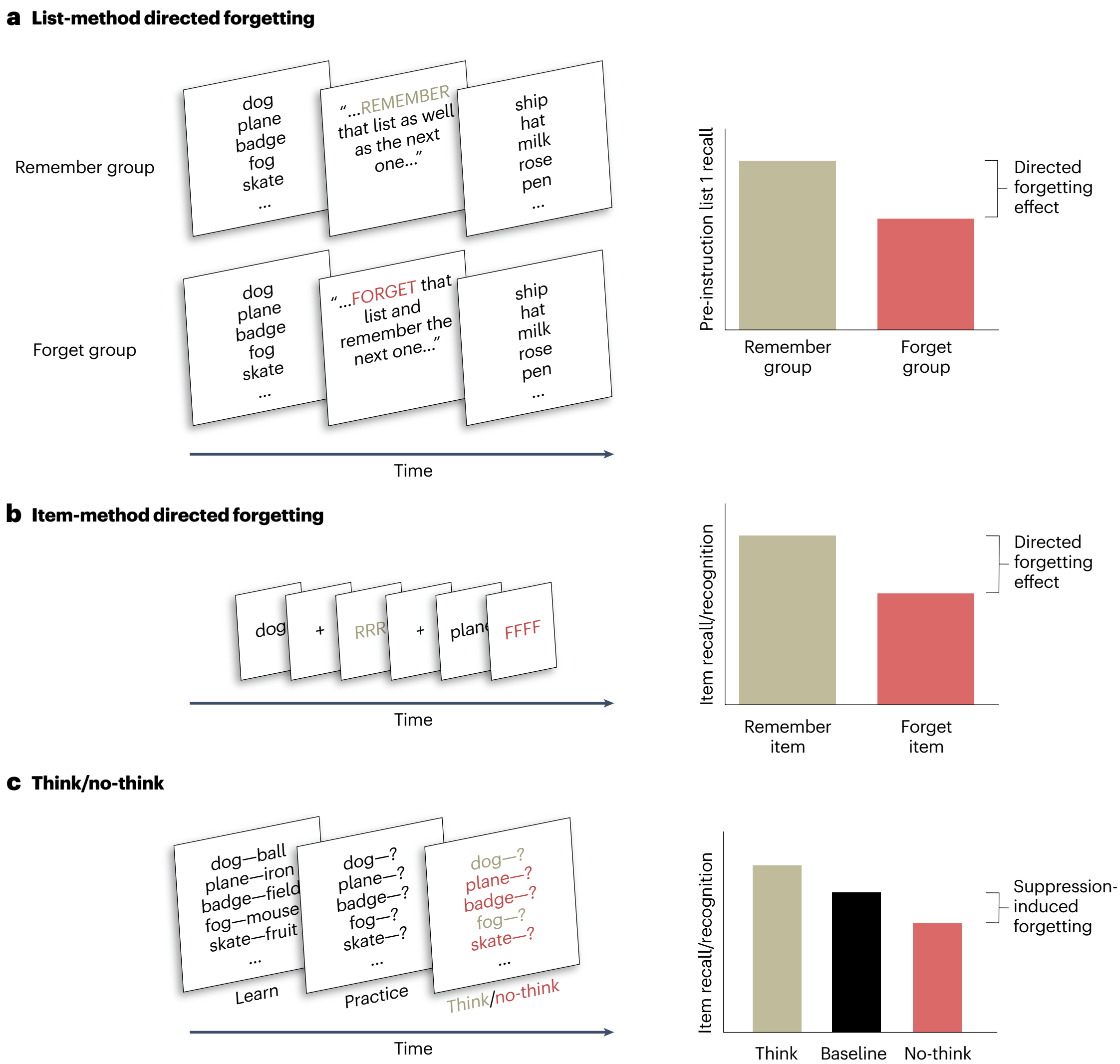

Fig. 1 | Paradigms used to study intentional forgetting in the laboratory. **a**–**c**, Example study phase and results for list-method directed forgetting (**a**), item-method directed forgetting (**b**) and think/no-think (**c**) paradigms. Participants are either instructed to remember or to think about items (brown); or they are instructed to forget or not think about items (red).

retrieval. When the encoding and retrieval contexts match, memory is better than when they mismatch[21–23]. The context change account of list-method directed forgetting centres around the idea that the change in mental context prompted by the mid-list forget instruction persists into the recall task, creating a mismatch between the retrieval context and the pre-instruction encoding context[13,24]. Accordingly, participants who received the forget instruction are worse at recalling the first half of the list than participants who received the remember instruction, for whom there was no mid-list context change[13]. According to this account, the list-method directed forgetting effect is more robust for recall than for recognition because presenting studied items again is thought to reinstate the study-phase context, eliminating the contextual mismatch. Under both conceptualizations of the results, list-method directed forgetting is attributable to changes in list accessibility at retrieval. The first half of the list is successfully encoded into memory and stored, so that the information is theoretically available, but owing to inhibition or a mental context change this information is not immediately accessible when the participant tries to retrieve it.

Whereas list-method directed forgetting involves changes in item accessibility, item-method directed forgetting is often thought to involve changes in item availability in memory. In other words, participants are unable to later recall or recognize to-be-forgotten information because it was not committed to memory in the first place. In an item-method paradigm (Fig. 1b), participants are presented with study items, one at a time, each followed by an instruction to remember or forget. This instruction occurs after each study item disappears, which means that participants must pay attention to and keep refreshing each item in working memory until the instruction is received[25–27], a process known as maintenance rehearsal. If the instruction is to remember, participants switch from maintenance rehearsal to elaborative rehearsal[26], which involves thinking about the word's meaning and connecting it to other long-term knowledge[28], which might also include the preceding to-be-remembered items. If the instruction is to forget, participants must stop the ongoing maintenance rehearsal[29] and prohibit any other rehearsal of the unwanted item. In this way, to-be-remembered items are selectively rehearsed over to-be-forgotten items and are therefore more likely to be available in memory for later recall and recognition[10]. A directed forgetting effect in an item-method task is defined as better subsequent memory performance for to-be-remembered items compared to to-be-forgotten items[8]. For recall tasks, this directed forgetting effect reflects both memory costs for to-be-forgotten items and memory benefits for to-be-remembered items[30]; for recognition tasks, it seems to reflect only costs for to-be-forgotten items[31,32].

It is relatively uncontentious that the item-method directed forgetting effect depends primarily – even if not exclusively[33–38] – on selective rehearsal of to-be-remembered items over to-be-forgotten items. However, there is debate over the mechanism that limits unwanted processing of items that participants intend to forget. One possibility is that people mentally segregate to-be-remembered items from to-be-forgotten items, dropping the latter from their rehearsal set[39]. The implication is that these to-be-forgotten items, which receive no further rehearsal, weaken or passively 'decay' over time until they are completely forgotten or inaccessible. Although the idea of memory decay has been a major theory of forgetting for over a century and seems to match subjective experience, it is not the preferred explanation for forgetting[40] and seems to be unable to account for item-method directed forgetting for two reasons. First, if participants are asked to respond as quickly as they can to a visual probe (such as an asterisk) that appears shortly after the memory instruction, they are slower to do so if the instruction is to forget than if it is to remember[41]. This counters the notion of forgetting being due to passive decay over time and instead suggests that trying to forget is even more cognitively demanding than trying to remember[42,43] – at least over the short term, soon after the instruction, even if not over the longer term[44,45]. Second, even if passive decay does augment the loss of information from working memory[46], and thereby contributes to a weaker[47] and more impoverished[43,48–50] representation in memory, intentional forgetting must be active to the extent that the participant must stop ongoing rehearsal of the item when presented with the instruction to forget[51]. Stopping is an action[16,52] that is executed to interrupt ongoing thoughts or behaviours[53]. There is some debate over whether the kind of cognitive action needed to stop unwanted mental rehearsal is inhibitory or non-inhibitory[54–56]. On the one hand, stopping unwanted rehearsal activates some of the same frontal lobe neural pathways that are activated when ongoing motor responses are inhibited and attention is shifted to other tasks[16,57–60]. Indeed, neuroimaging studies often point to inhibitory control as a mechanism for forgetting in the item-method paradigm[27,61–65]. On the other hand, behavioural evidence suggests that stopping ongoing rehearsal might be analogous to stopping unwanted motor responses[29] but is not identical[66].

Instead of inhibiting rehearsal directly, it is possible that the observed frontal lobe activation reflects changes in attention linked to frontal-parietal and frontal-hippocampus neural networks[67]. This pattern could account for evidence that instructions to forget seem to prompt a withdrawal of attention from the to-be-forgotten item held in working memory[68–72]. Such a withdrawal of attention could halt further processing and elaboration of the to-be-forgotten item, making that item relatively less likely to be encoded into long-term memory than a to-be-remembered item that remains in the spotlight of attention. Although this withdrawal of attention might be cognitively effortful in the relative short term – accounting for the longer reaction times needed to respond to visual probes that follow forget instructions compared to those that follow remember instructions – it seems likely that the purpose of this withdrawal is ultimately to make limited-capacity resources available for redeployment to other task-relevant activity[73,74]. That said, there is evidence that the visual and linguistic context in which a to-be-forgotten item was studied continues to be represented[75,76], suggesting that the end-result of trying to forget might instead be an 'unbinding' or separation of the to-be-forgotten item from a memory of the context in which it was studied[48]. Unbinding of an item from its context could be aided by rapid encoding of the context prior to the memory instruction[75,76] and subsequent withdrawal of attention from the study item after a forget instruction. Nevertheless, any forgetting that occurs owing to a shift of attention away from the to-be-forgotten item cannot be enhanced by giving participants something new to focus on instead of the to-be-forgotten item – if that were so, then replacing the to-be-forgotten word with a new to-be-remembered word would result in even more forgetting than when no new item is offered[77,78]. That forgetting is not increased by requiring participants to redirect attention to a new item argues that changes in attention must be a consequence of trying to forget, rather than the sole mechanism by which such control is achieved[32,41,66,70,71]. Whatever the mechanisms involved, an item-method paradigm prompts participants to control encoding processes to limit the formation of unwanted long-term representations.

The third major paradigm used to study intentional forgetting in the laboratory is the think/no-think paradigm (Fig. 1c). Participants first learn and then practise a series of reminder–target pairs (such as 'dog–ball') until the reminder ('dog') reliably produces the target ('ball') to a set criterion (such as 66%). Participants are next presented with a subset of the reminder items and instructed to practise retrieving the target item ('think' trials) or to avoid retrieving it ('no-think' trials). Finally, participants are tested for their memory of all reminder items, including baseline items that were not presented on the think/no-think trials. A suppression-induced forgetting effect is defined as worse memory for the no-think items compared to the baseline items. Critically, this effect is also observed with new reminders, which are usually semantic associates of the target but were not practised (such as 'basket' to prompt 'ball'; independent probe test), which provides compelling evidence that it is the no-think target item representations that are suppressed and not the associations between the reminder and target items (for a review see ref. 17, but for an alternative explanation of this effect see refs. 79,80).

The think/no-think paradigm requires that participants engage top-down control to stop unwanted retrieval[9]. The suppression-induced forgetting effect observed in this paradigm is generally thought to involve two processes[16]. First, a proactive control mechanism prevents the unwanted memory of the target item from coming to conscious awareness when the reminder is presented on a no-think trial. Second, a reactive control mechanism withdraws attention from unwanted targets should they escape proactive control and intrude into mind. The proactive control mechanism activated in the think/no-think paradigm is associated with motor stopping and – similar to item-method directed forgetting – prompts neural activations in common with motor-stopping processes[16,17,81]. It might be that the reactive control mechanism needed to disengage from an intrusion also share with item-method directed forgetting the need to withdraw limited-capacity attentional resources, although this remains to be determined.

Enacting proactive and reactive control mechanisms in the think/no-think paradigm involves one of at least two general strategies – focusing on the reminder and otherwise keeping one's thoughts blank (directed suppression) or retrieving a competing memory associated with the reminder as a distraction (thought substitution). Although each strategy is thought to have unique neural correlates[82], they produce comparable effects and might even be derived from common processes[83–85]. One perspective is that when a memory is triggered but fails to gain complete internal focus, leaving it in a 'moderate' state of activation (meaning that the memory is not quite occupying one's thoughts), the brain destabilizes that memory, making it harder to bring to mind in the future[86]. This process is thought to reduce competition for limited-capacity processing resources and discourage the same unwanted thought from repeatedly interfering with mental tasks. In the think/no-think paradigm, it does not matter whether the memory is kept from coming to mind by keeping one's mind blank or by thinking of something else: the outcome is the same.

No matter which paradigm that is used to study intentional forgetting in the laboratory – list-method directed forgetting, item-method directed forgetting or think/no-think – one thing is clear. People have the ability to influence what they encode and later retrieve from their own memories. Whether an instruction is to forget rather than remember, or to not think rather than think, there are measurable changes in subsequent memory performance. These changes demonstrate the adaptability of human memory and emphasize that forgetting, like remembering, requires active cognitive control.

Everyday intentional forgetting

The item-method directed forgetting paradigm and the think/no-think paradigm engage mechanisms that actively limit encoding or retrieval of unwanted memories, which makes both paradigms particularly relevant to a consideration of how control over memory might be engaged in the real world. The list-method paradigm also has application in the real world because changes in mental context would seem to be a frequent source of real-world forgetting. For example, a person might mentally or physically retrace their steps when trying to find misplaced keys, trying to reinstate the context in which they last knew of the location of the keys. However, in real-world applications, individuals seem more likely to use context reinstatement to avoid or overcome forgetting – such as when retracing their steps to find misplaced keys – rather than to intentionally forget in the first place. An exception might be when a person attempts to control their mental context by distracting themselves with another thought[83–85]. However, compared to the kind of context change that is implicated in list-method directed forgetting, this approach seems less likely to involve complex alterations of mental time or space. Accordingly, in the following discussion, we focus on the relation between everyday intentional forgetting and forgetting in item-method directed forgetting and think/no-think paradigms only.

There are many examples of item-method directed forgetting and suppression-induced forgetting that are relevant to everyday life[87]. For instance, item-method directed forgetting comes up in jury trials – a judge might direct the members of the jury to disregard inadmissible testimony that they have just heard[88]. Likewise, in casual conversation, the listener might need to forget an erroneous phone number after the speaker accidentally provides an outdated one[89]. Suppression-induced forgetting is relevant when a person tries to actively stop thinking about and ruminating on a past event or regret. Over time and with repeated attempts at suppressing retrieval when faced with a reminder, experiences that were initially overwhelming can become less detailed, less emotionally pressing and less likely to intrude[90].

One of the most important functions of memory is to enable a current and up-to-date understanding of the world, and many of the mechanisms relevant to intentional forgetting might be understood as 'updating' mechanisms aimed at expunging information that is no longer wanted (because it is irrelevant or maladaptive) in favour of new information or a new perspective. However, there might be times when memory updating would be better served by retaining – rather than forgetting – outdated, irrelevant or misleading information. For example, when faced with incorrect directions or a biased news article it is sometimes helpful to remember the incorrect elements so as to avoid their influence in the future[91,92]. Likewise, there are times when forgetting updates memory so successfully that it hampers mental health. For example, depression can be worsened when people have trouble accessing memories of past behaviours that could otherwise challenge their current negative views of themselves[93]. And, even when intentional forgetting might be appropriate in a particular situation, people vary with respect to their ability or willingness to actively forget, owing to a biological predisposition to struggle with such control efforts[94,95], a meta-cognitive thinking style that leads them to dwell on unwanted memories[96], or even the nature of the information that they intend to forget. With respect to thinking styles, meta-cognitive theories of worry and rumination suggest that some individuals choose to return to painful experiences or future events[97], rather than intentionally forget, because they believe that re-hashing negative experiences or thoughts will produce solutions to their problems. However, solutions generated by rumination or worry tend to be of poor quality and/or are unlikely to be implemented[98]. Furthermore, the intentional retrieval of those thoughts leads to future intrusions and worsens clinical symptoms[99]. This negative impact can be compounded by the fact that highly arousing, negatively valenced experiences are those most likely to be the target of both rumination and emotional regulation efforts but can be the hardest to forget[100].

The important part played by forgetting in everyday memory updating and emotional regulation is perhaps best demonstrated by instances in which forgetting processes fail. Although hyperthymesia[101] is quite rare, other more common conditions highlight the detrimental everyday effects of impaired forgetting. These conditions include generalized anxiety disorder, obsessive-compulsive disorder, and post-traumatic stress disorder[85,95]. Being unable to push from mind distressing worries, obsessions or personal traumas when faced with a reminder can lead to hardships in daily life[101,102]. People with these diagnoses – and other conditions that are characterized by recurrent, unwanted thoughts or memories – often exhibit impaired control processes in laboratory paradigms[85,95]. As a consequence, some theorists suggest that being trained to intentionally forget might provide an additional route to remediation for disorders characterized by unwanted thoughts[103].

Despite the importance of exerting cognitive control over memory, even when such control can be exercised, it is not always possible to expunge all unwanted experiences from memory. Indeed, intentional forgetting is undermined by most manipulations that are known to improve memory. For example, in the laboratory, people are better at remembering but worse at forgetting pictures compared to words, and better at remembering but worse at forgetting words that they read aloud from a list compared to those that they read silently[104,105]. In a similar way, some everyday experiences are easier to remember and harder to forget than others. For example, someone might be successful in not thinking about their former partner until they hear a formerly treasured song that brings up unwanted memories. Laboratory studies explain this effect by showing that it is nearly impossible to suppress retrieval of an unwanted experience if the reminder is strongly associated with that memory and if repeated retrieval further strengthens that link[86].

In laboratory-based directed forgetting studies, people have an impressive ability to exert encoding and retrieval control over many different kinds of stimuli – including faces[106–108], un-nameable visual symbols[109], multicoloured spiral images[50], complex pictures[31,110], videos[43,49] and autobiographical events[111,112] – but this control is not absolute. As noted above, some material – like pictures versus words or words read aloud versus silently – 'stand out' in memory owing to their distinctive encoding and thereby frustrate attempts to exert control over encoding[104]. Laboratory studies also reveal that memories are sometimes formed for things one intended to forget[50] – and at a higher rate than for items for which there was no memory intention at all[113]. Curiously, this unwanted encoding increases the more time that one has available to actively try to forget[114], and the mere attempt to forget can in some cases lead to mental representations that capture a general sense (or gist) of the to-be-forgotten information, such as remembering that a video showed a baker adding cornstarch to a batch of cookies, but that lack specific details, such as forgetting the amount of cornstarch that was added[43,49,50,115,116].

These findings suggest that in everyday memory, successful updating might depend not only on intentionally forgetting unwanted information, but also on retaining some of that unwanted information in an altered state – morphed from specific details into a more gist-based representation. It seems possible that retaining a gist-based representation of to-be-forgotten information might enable more continuity between past and present experiences than might otherwise be possible if forgetting were absolute. At the same time, morphing specific details into a gist-based story might make formerly negative memories more approachable, ultimately enabling one to review them from a more objective point of view and to integrate them with one's broader life story such that commonalities with other experiences might then emerge. Speculatively, the tendency for to-be-forgotten information to be represented in general gist form instead of in fine detail might provide a way for unwanted information to be updated, re-written and shaped to create the kind of negative space needed to bring more up-to-date information into focus; to find better, more creative solutions to pressing problems; or to develop more effective coping strategies.

Limitations in the ability to forget emphasize the interplay between experience and control in determining what is encoded into and retrieved from long-term memory. Perhaps the experiences that are not amenable to control serve as the basic outline of each person's self-narrative, with the ability to forget some details and to not think about some experiences providing one with the opportunity to flesh out this skeletal outline with intention and agency, as an author of their own self-narrative. Indeed, in the laboratory, intentionally forgetting a conflict makes participants more likely to subsequently forgive an offender, compared to when they try to remember that conflict[117]. And after a hypothetical transgressor has been forgiven, a no-think instruction suppresses more details of the incident than when the transgressor has not been forgiven[117]. Participants are able to forget negative references to themselves, even if not as easily as they can forget negative references to other people[118]. And when participants are instructed to forget ambiguous information, they are more likely to later judge that information as false than if they were instructed to remember it[119]. These findings are indicative of some of the ways that intentional forgetting might operate in everyday life to shape a person's relationships with others, that person's own self-image and their beliefs about the world.

Laboratory-based unintentional forgetting

Whereas we have been describing forgetting that people do on purpose, forgetting can also be unintentional, such as trying and failing to recall the name of a new acquaintance or the correct answer on a test. Although this forgetting can feel random and affect experiences that one tried hard to remember, patterns of unintentional forgetting can be studied in the laboratory. In the examples above and in induced-forgetting paradigms[14,15], people predictably forget information that is related to information they successfully remember.

Induced forgetting was first studied using the retrieval-induced forgetting paradigm[14] (Fig. 2a). In this paradigm, participants first encode a list composed of categories of words, such as different animals, fruit and hobbies, presented alongside their category label (for example, 'FRUIT: apple'). After this study phase, participants retrieve a subset of these studied words from half of the studied categories in a practice phase (for instance, practising some fruit but no hobbies). This retrieval practice is typically accomplished through cued recall, in which participants are asked to complete word stems with an encoded word from the study phase (for example, 'FRUIT: ap_' → 'apple'). Finally, participants are tested on their ability to recall encoded words from the study phase. Participants remember practised words better than unpractised words from different categories (baseline words): this is termed the practised effect[120]. However, participants have even worse memory for unpractised words in the same category as practised stimuli (such as 'pear', a fruit that was not practised). Worse memory for categorically related words, relative to baseline words, is the hallmark of this paradigm and is termed the retrieval-induced forgetting effect.

Memory theorists have proposed several opposing accounts to explain induced forgetting. The inhibition theory asserts that inhibitory mechanisms underlie forgetting[121,122]. The act of retrieving some memories – such as the word 'apple' – in the practice phase leads to the activation of memories within a category (such as all the studied fruits). Given this widespread activation, locating and selecting the correct fruit in memory requires inhibition of the activated but non-target fruits, such as 'pear'. This inhibition endures into the test phase and causes difficulty in remembering non-target fruits. A second theory, the competition theory, posits that when an item is retrieved from memory, the trace (memory representation) of that item is strengthened[123]. For example, the trace of 'apple' becomes stronger every time participants practise retrieving this word when cued with the category 'FRUIT'. The consequence of strengthening targeted memories through practice is that when memory is tested for non-practised items from the same category (such as 'pear'), the stronger traces for the practised items create competition and thereby interfere with the retrieval of the non-strengthened items. Thus, what looks like forgetting is the inability to access weaker traces because stronger traces are more likely to 'win' the competition for retrieval. A third theory, the context theory, of induced forgetting states that the root cause of forgetting might be the contextual nature of memory[124]. Because episodic memories are bound to the context in which they were encoded, re-evoking that context during retrieval can aid in retrieving that memory. It has been proposed that the changes in task between each phase of the induced-forgetting experiment causes an internal mental shift in the participant, creating distinct contexts[24]. When searching memory for a target item in the test phase, the most temporally recent context in which the category was encountered would be activated. For practised categories, that means that the

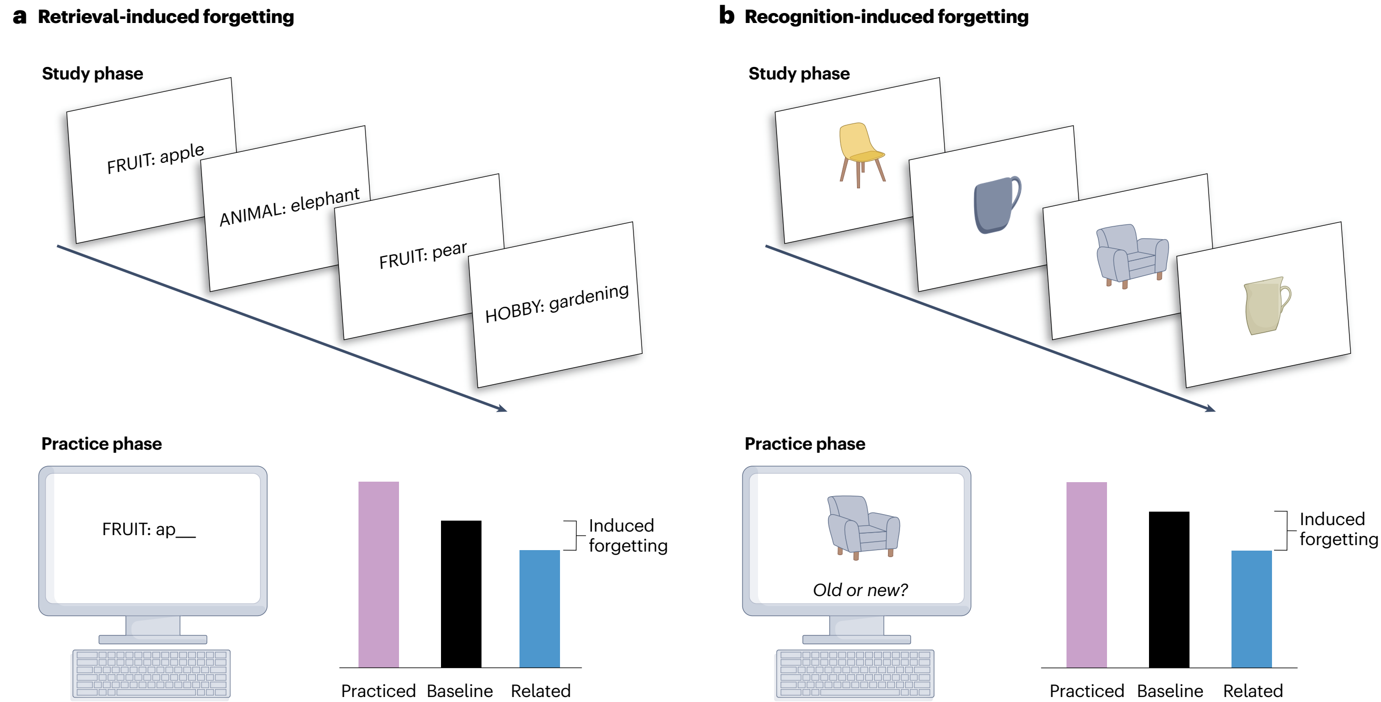

Fig. 2 | Paradigms used to study unintentional forgetting in the laboratory. **a**, The retrieval-induced forgetting paradigm consists of study, practice and test phases, shown here for paired category-exemplar words. Typical results in the test phase are: best memory for practised words, then for baseline items (non-practised categories) and then for related items (non-practised category items). **b**, The recognition-induced forgetting paradigm consists of study, practice and test phases, shown here with pictures of objects from different categories (chairs and mugs). Typical results in the test phase are: best memory for practised objects (practised chairs), then for baseline items (mugs) and then for related items (non-practised chairs).

practice phase is activated. However, because non-target items from the practised categories are not in the practice phase, they do not benefit from this activation and are therefore less likely to be retrieved at test.

The inhibition theory of induced forgetting was tested in a modification of the retrieval-induced forgetting paradigm, known as the recognition-induced forgetting paradigm[15] (Fig. 2b). In recognition-induced forgetting, items are presented sequentially on a screen for study. Category labels are not necessary when the items are pictures because a picture of a blue vase inherently activates the category 'vase.' Then, instead of a cued recall task, the practice and test phases require that participants recognize whether each item was previously studied ('old') or not ('new')[15]. An advantage of this paradigm is that re-presenting an item to study is sufficient to drive a recognition response, meaning that engaging in restudy in the practice phase leads to forgetting[125]. Leveraging restudy to induce forgetting, the inhibition account can be tested by presenting participants with a long sequence of objects, one at a time in a continuous stream, some of which repeat mid-stream. According to the inhibition account, repeating some objects mid-stream means that early-stream items from the same categories as the repeated objects should be inhibited (by recognition-induced forgetting) whereas late-stream items, which have not yet been presented at the time of repetition, should not be inhibited (Fig. 3). However, unpublished work finds that memory for early-stream objects belonging to repeated categories is statistically indistinguishable from late-stream items on a subsequent memory test (A.M.M., R. A. Cutler, R. M. Nosofsky & R. M. Shiffrin, unpublished work). These results are challenging to explain from an inhibition perspective, because inhibition should unfold across the temporal sequence of objects being presented. Specifically, as one item in a category repeats, the earlier items should be inhibited relative to those that have not yet been presented. Accordingly, induced forgetting seems more likely to be caused by competition[123,126–128] and context mechanisms[24,129]. Neither the competition nor context account require that the early-stream items be any weaker than the late-stream items, given that neither were repeated and the order of item presentation does not matter for these accounts.

Although ongoing work examines the underlying mechanism that actively induces forgetting, laboratory unintentional forgetting is clearly a robust effect, spanning both word and picture stimuli and operating across recall and recognition. Induced forgetting paradigms demonstrate that forgetting occurs not only through active efforts to intentionally forget or to not think about unwanted information: forgetting also occurs unintentionally, as a consequence of actively attempting to retrieve or recognize other, related, information stored in long-term memory. And the varied circumstances under which unintentional forgetting has been shown indicates that this forgetting mechanism is not isolated to the laboratory.

Everyday unintentional forgetting

Although the mechanism underlying unintentional forgetting continues to be debated, the prevalence of this type of forgetting in everyday life is clear. The retrieval-induced and recognition-induced forgetting laboratory paradigms – which involve associating specific items with their category – mimic our natural memory system, which is also based on categories[130–132]. Indeed, if there is no pre-existing knowledge

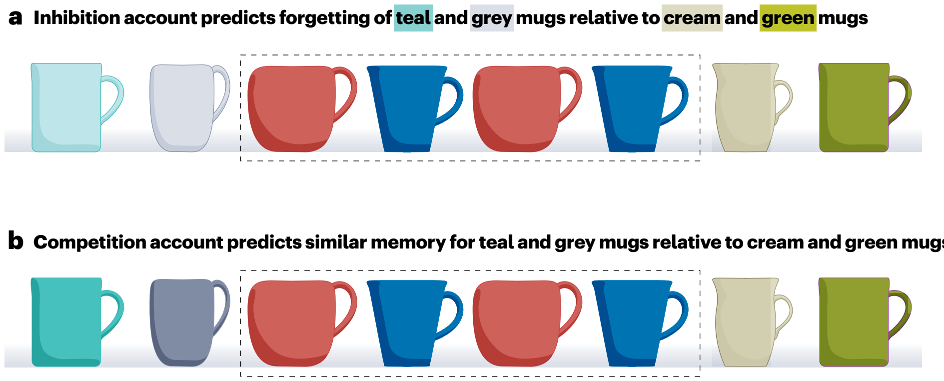

Fig. 3 | Testing accounts of unintentional forgetting. Participants were presented with a stream of items, some of which were from the same category. In the middle of the list, some items are repeated (red and blue mugs). According to the inhibition account, the early-list mugs (teal and grey) would be suppressed relative to the late-list mugs. According to the competition account, memory should be similar for the teal and grey mugs relative to the cream and green mugs. Consistent with the competition account, memory for early-list items was statistically indistinguishable from late-list items. Figure concept adapted from work presented at the 2021 Annual Meeting of the Psychonomic Society by A.M.M. et al. (unpublished).

(such as a category or other category members) to tie to incoming information, it is more likely to be forgotten[133–135].

Although the range and realism of the memories that are affected by induced forgetting paradigms reveals the impact of unintentional forgetting outside the laboratory[136–140], some forgetting studies more closely mimic everyday scenarios. For example, one induced-forgetting study had university students study research articles and then tested their knowledge, similar to what occurs in psychology classes[141]. Participants read two psychology articles, verbally practised the material from one of the articles, and then were tested on their memory for both articles using a test booklet. The authors found that participants forgot material related to the questions that were verbally practised, a retrieval-induced unintentional forgetting effect. Although not every scenario from the real world has been tested in the laboratory, there are many everyday scenarios that are similar to laboratory paradigms. For example, unintentional retrieval-based forgetting is likely to occur for a memorized grocery list. Because the list is composed largely of food and ingredients from the same or similar categories, retrieving one of those items from memory while shopping could cause forgetting of other items on the list. Similarly, after attending a meeting with many new faces (such as a new class or book club), later recognizing one of those faces in another context could cause someone to forget the other newly encoded faces. The large variety of categories that induced forgetting operates on in the laboratory means that there are many scenarios in everyday life in which induced forgetting might occur.

Induced forgetting can also occur in critically important real-world scenarios. Imagine you witness the escape of a bank robber, weapon in hand, in a getaway car driven by another person. Even though forgetting or inaccuracies in this eyewitness memory could potentially lead to the robber not being charged or the wrong person imprisoned, memories for these events are probably susceptible to induced forgetting (Fig. 4). For example, correctly identifying the getaway car driver from a lineup is akin to remembering a subset of a category, because it is one face of the two relevant faces in memory. The act of identifying the getaway car driver (the practised stimulus) could lead to forgetting the appearance of the armed robber (the related stimulus) if the armed robber is not caught until later and memory for their appearance is not retrieved until after memory for the getaway car driver is strengthened. Similarly, laboratory studies mimicking real-world crime scenes have found that recalling an item from one of these scenes impairs memory for its other items[142,143]. For example, in one of these studies, participants were instructed to study the items within two scenes (presented as 'crime scene' slides) as if they were a police officer responding to two separate home burglaries[143]. Participants then answered questions in a booklet about half of the items from one of the scenes, which impaired memory for the untested items from that scene.

One might think that an eyewitness to a crime could be impervious to unintentional forgetting because eyewitnesses have a known tendency to focus on certain details, such as weapons, when present during a crime[144,145], presumably improving memory for these details relative to mundane stimuli in a laboratory experiment. However, even experts on recognition-induced forgetting, or participants trying to overcome the forgetting, are unable to prevent forgetting from happening[146].

Forgetting across settings

Although both unintentional and intentional forgetting can occur across the spectrum from unimportant to critical importance, these types of forgetting have different impacts. Whereas the unintentional forgetting of information is often what people claim to be minor memory issues in everyday life, the intentional desire to forget might bring a client to seek help from a clinician (for instance in cases of wanting to forget traumatic memories). Beyond differing in the severity of how instances are usually perceived in everyday scenarios, the paradigms used to study intentional and unintentional forgetting also differ.

A comprehensive application of laboratory studies to everyday forgetting necessitates connecting the classically segregated approaches to intentional and unintentional forgetting. For instance, one study that examined the magnitude of forgetting across intentional directed forgetting and unintentional induced forgetting in the same participants found that performance was correlated between the two tasks and unintentional forgetting was larger[147], which implies that although the two may share overlapping causes (such as cognitive control processes), these causes are more effective (or more effectively implemented) for unintentional forgetting, at least in the laboratory. Worse intentional forgetting relative to unintentional forgetting might not be surprising, given that one can easily imagine circumstances under which the intention to remember or forget fails. Indeed, when participants are instructed to exert volitional control over unintentional forgetting, they are unable to prevent the forgetting effect, even when those participants are researchers well acquainted with the paradigms and mechanisms involved[146]. Speculatively, this finding suggests that patients and clients presenting with clinical needs to forget might at times be better served by treatments implementing unintentional forgetting methods rather than intentional forgetting methods – particularly if these individuals are otherwise deficient in the processes needed to exert volitional control. Indeed, as clinical applications of forgetting demonstrate mental health benefits – such as a reduction in anxiety following memory suppression training[103] – the magnitude, circumstances and ecological validity of both intentional and unintentional forgetting remain central to the development of effective treatments.

Evaluating frequent themes across intentional and unintentional forgetting studies reveals insights into forgetting more broadly. Overlaps in proposed underlying mechanisms across the different types of intentional and unintentional forgetting help to disentangle the consequences of forgetting from the mechanisms of forgetting. For example, evidence of inhibitory mechanisms[61,122] and context effects[13,24] occur in studies of both types of forgetting and are conceptualized as distinct potential mechanisms. Therefore, perhaps the most notable way the separate forgetting research traditions can learn from one another is in the potential role of attention in contextual and inhibitory models of memory.

First, consider the role of attention in context models of memory. Intentional[12,13] and unintentional[24,129] forgetting both seem to be affected by mental context, following decades of research on the role of context in memory[13,22,24,129,148–150]. The Context Maintenance and Retrieval Model (CMR3) of memory can account for both intentional free recall and unintentional intrusive memories[151]. A cognitive control mechanism included in the model uses context similarity to reactivate and suppress information in memory that is either near or far from the locus of attention. Critically, the model does not articulate whether this cognitive control mechanism is intentional or unintentional, so it is possible that attention has a role in a context explanation of both intentional and unintentional forgetting.

Next, consider the role of attention in linking mechanisms of intentional forgetting with proposed inhibitory mechanisms of unintentional forgetting. As described above, a withdrawal of encoding resources occurs following a forget instruction in an item-method task, and perhaps is also engaged reactively by an intrusion on a no-think trial. Just because this change in attention is prompted by volitional control – the intention to forget or the desire to not think – does not mean that unintentional forgetting, which operates outside explicit cognitive control, must have a wholly separate underlying mechanism. Attention can be oriented towards or away from something (in one's environment or mind) intentionally or unintentionally, with consequences for the encoding, retrieval and representation of the information in question. Indeed, an inhibitory account of suppression-induced forgetting and retrieval-induced forgetting suggests that attention and inhibition work together to support forgetting, causally linking the prefrontal cortex to induced (and therefore unintentional) forgetting[152]. Inhibitory control is therefore not only dependent on attention for unintentional forgetting but seems also to be attentionally dependent in intentional forgetting, with control processes mediated by the prefrontal cortex implicated in intentional forgetting in both human and non-human animals[153–155] and enabled by inhibitory γ-aminobutyric acid (GABA) neurotransmitters[81].

Clearly, intentional and unintentional forgetting differ in many ways – including in how severe instances are usually perceived to be – yet studying these types of forgetting in the laboratory and considering their influence in everyday memory suggests important commonalities that might ultimately be connected by common underlying mechanisms. From potentially overlapping mechanisms and explanations to implications for disorders characterized by unwanted thoughts, any comprehensive theory of forgetting must account not only for how either is studied in the laboratory, but also for how it is implemented in everyday life.

Summary and future directions

We have brought together the findings of research into laboratory-based and everyday intentional and unintentional forgetting to generate a broader understanding of forgetting in episodic memory. We have reviewed typical paradigms used to study intentional and unintentional forgetting. List-method directed forgetting, item-method directed forgetting and think/no-think paradigms have reliably demonstrated that intentional forgetting is robust and can result from cognitive control mechanisms attributed to inhibition, attention and mental context change. Retrieval-induced and recognition-induced forgetting paradigms demonstrate that unintentional forgetting operates over

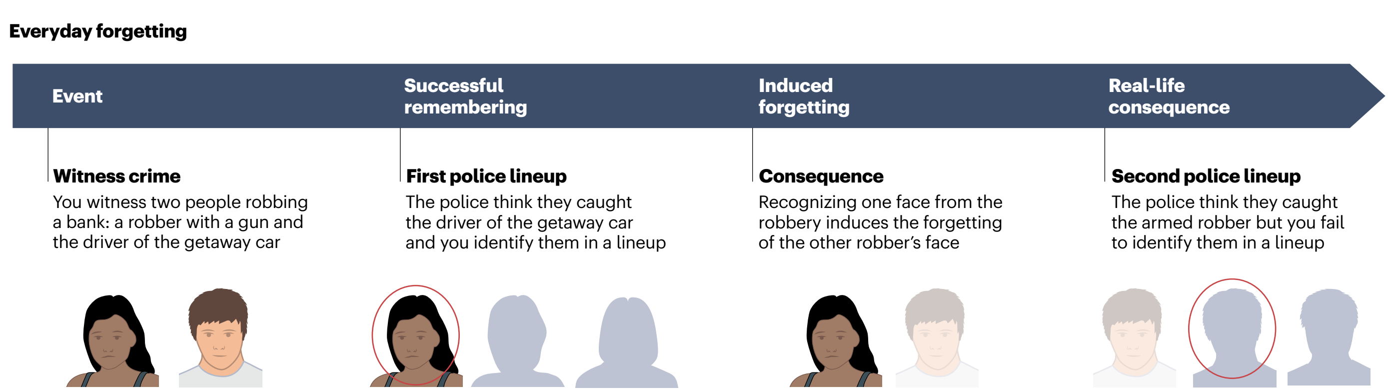

Fig. 4 | Everyday forgetting. Induced forgetting can occur outside the laboratory in this example of everyday forgetting. The act of successful remembering of one aspect of a memory (the identity of the getaway driver) might result in induced forgetting for the identity of the robber, leading to a failure to recognize them in a later test.

categories of items and probably involves context as well as interference or inhibitory mechanisms. Each of these types of forgetting occurs in the real world, where forgetting can be intentional (for instance, 'I want to forget that disconnected phone number') and/or unintentional (for instance, 'I can't remember my bank PIN'). Seeking connections and commonalities between these typically isolated areas of study is an important step in understanding not just forgetting but broader human cognition.

The further combined study of these paradigms in real-world contexts could have profound impacts in terms of clinical applications. For example, the induced forgetting paradigm can be extended into the real world by creating applications that invite users who want to forget a memory to upload their own images, tagged to indicate which should be forgotten and which should be remembered. Using pictures from a user's own camera roll prompts important questions about whether personal experience with images used in an intentional forgetting task can be forgotten at the same rates as shown in laboratories. Studies of intentional forgetting of personal memories (generated by – rather than provided to – participants) are promising in this respect, demonstrating a reduction in the aversive nature of not only past experiences but also future worries[116,156–159]. These studies reflect an important shift in the direction of the field – but more can still be done. In this respect, an important future direction is to study forgetting in a more ecologically valid manner either using personally relevant experiences (as above) or using virtual/augmented reality or planned events (such as a structured but natural activity) to create realistic experiences to which forgetting can be applied. Likewise, whereas it has been shown that individuals who report difficulty controlling unwanted memories in everyday life exhibit impaired forgetting in laboratory tasks, further efforts should be made to characterize forgetting processes in individuals likely to experience trauma (such as first responders). Characterizing forgetting prior to those experiences could help to determine whether laboratory-based forgetting paradigms are capable of predicting who is at greatest risk of developing conditions such as post-traumatic stress disorder (PTSD), so that protective measures might be taken. In short, mechanisms founded in the laboratory show promise as potential targets for intervention when applied to real-world settings. The clinical applications of studies such as these – including recent findings that laboratory-based training protocols can improve self-reported clinical indices in clinical populations[103] – raise hope for accessible, theory-driven interventions within reach for anyone with a smartphone.

Combining the study of traditionally siloed types of forgetting could also lead to a unified theory of forgetting. The most compelling explanation of forgetting will be a combination of factors that are believed to affect both intentional and unintentional forgetting, and will need to unite the roles of attention and inhibition[61,122] with changes in context[3,22,24,135,148–150]. Future efforts might consider adopting the sort of structural equation or factor analytic approaches that have proved useful in developing typologies of executive function[160,161] and general intelligence[162,163]. Such efforts would necessarily include a broad variety of forgetting measures – spanning both unintentional and intentional, as well as active and passive – alongside measures of attention and broader inhibitory control, to characterize the interrelations between these concepts in the hopes of distilling their commonalities and latent structure. That individuals with disorders characterized by an inability to control unwanted thoughts tend to show deficits in both laboratory-based intentional and unintentional forgetting tasks[85,95,164] provides enticing evidence that common processes are involved, and this insight has real-world implications. Theories of intentional and unintentional forgetting must be able to account for this finding, with the principle of parsimony favouring models capable of explaining both in common terms.

In conclusion, identifying models of forgetting that can be implemented across a wider variety of circumstances and explain consequential experiences will lead to valuable testable hypotheses about broader constructs such as memory and attention. Indeed, studying forgetting in isolation misrepresents the highly complex and interrelated nature of human cognition.

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