Attentional Switch to Memory: An early and critical phase of the cognitive cascade allowing autobiographical memory retrieval

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Abstract

Remembering and mentally reliving yesterday's lunch is a typical example of episodic autobiographical memory retrieval. In the present review, we reappraised the complex cascade of cognitive processes involved in memory retrieval, by highlighting one particular phase that has received little interest so far: *attentional switch to memory* (ASM). As attention cannot be simultaneously directed toward external stimuli and internal memories, there has to be an attentional switch from the external to the internal world in order to initiate memory retrieval. We formulated hypotheses and developed hypothetical models of both the cognitive and brain processes that accompany ASM. We suggest that gaze aversion could serve as an objective temporal marker of the point at which people switch their attention to memory, and highlight several fields (neuropsychology, neuroscience, social cognition, comparative psychology) in which ASM markers could be essential. Our review thus provides a new framework for understanding the early stages of autobiographical memory retrieval.

Keywords

autobiographical memory, episodic memory retrieval, mental time travel, attention, attentional switch, default mode network, perceptual decoupling, gaze aversion

1. Introduction

Autobiographical memory retrieval allows humans to remember the personal events they have experienced in their lives (Conway, 2001). Retrieval from memory requires a complex cascade of cognitive operations. Although the cognitive processes involved in autobiographical memory have been extensively studied, the *earliest* phase has been largely overlooked, leading to incomplete models of autobiographical memory. We, therefore, focused the present review on the switch of attention from the external to the internal world that takes place at the onset of strategic autobiographical retrieval. Without this early attentional switch, strategic autobiographical memory cannot occur. The three main goals of the present theoretical review were to turn the spotlight on this critical phase of autobiographical retrieval, clarify its neural correlates, and formulate hypotheses about objective behavioral markers that could bring about new advances in the field.

We cross-referenced knowledge about two different domains: episodic autobiographical memory retrieval (reminiscing about personal past events), and attention (ability to focus on objects or thoughts). More specifically, we looked at how the dichotomy between internal and external attention (Chun et al., 2011) can explain how the retrieval of information from autobiographical memory is initiated. As attentional resources are limited, internal attention and external attention compete for the same resources (Smallwood & Schooler, 2006). To enable retrieval from autobiographical memory, attention has to be disengaged from the external world and redirected toward an internal mental world containing thoughts and memories (Chun et al., 2011). Attention, therefore, needs to be switched from the external to the internal mental world. We call this moment the *attentional switch to memory* (ASM). Because external and internal attention depend on anticorrelated and mutually exclusive brain networks (Fox et al., 2005), ASM causes a transition between these two brain states. We can assume that a major change in brain activity takes place at the same time. We explore this major functional reorganization of the brain, with a special focus on the regions thought to act as switchboards between the two attentional networks. Last, we suggest that ASM is accompanied by objective measurable temporal markers. These behavioral (oculomotor) markers could be critical for different fields of research (Box 1).

2. Autobiographical memory retrieval

Autobiographical memory concerns personal memories and subtends the sense of identity and continuity (Conway, 2001). It is an essential cognitive ability for humans who spend a great deal of their time mentally reliving personal events they experienced in the past. For example, autobiographical memory retrieval is a prerequisite for resolving memory issues (e.g., “Where did I put my keys?”) and joint reminiscing (e.g., “Do you remember that restaurant we went to in Paris some years ago?”).

Historically, Tulving’s proposal has distinguished two components within personal memory: an *episodic* component, concerning specific, contextualized memories about personal past events, and a *semantic* one, taking the form of general knowledge about the self (Tulving et al., 1988). Although this episodic-semantic distinction has recently been thought of as less strict than it was initially proposed (Renoult et al., 2019), it remains an influential view. Episodic memory is about relatively brief events that have occurred only once, in a given place and at a defining moment. To retrieve such information, *mental time travel* (Tulving, 1972, 2002) is required, that is an ability to mentally relive one's own past experiences (Perrin & Michaelian, 2017; Suddendorf, 2007). This is accompanied by a specific type of *autonoetic* consciousness that involves a strong subjective sense of self (Tulving, 2002) and which can be viewed as an epistemic feeling of pastness (Moulin & Souchay, 2013; Perrin et al., 2020). Episodic autobiographical memory retrieval is thus not only characterized by the content of the retrieved memories, but also by this unique subjective experience of reliving past events (Tulving, 2002).

S*trategic* (indirect) retrieval is an intentional and active search of memory for elements that will allow the target event to be reconstructed. It is therefore voluntary, sometimes effortful, and involves top-down attention. This contrasts with *associative* (direct) retrieval, which refers to events that spontaneously come to mind when a cue (i.e., internal thought or element of the environment such as the smell or sight of an object, e.g., Proust’s madeleine) automatically reactivates a memory trace (Moscovitch & Winocur, 2002).

Strategic autobiographical memory retrieval is a dynamic process that goes through distinct phases. It is essential to distinguish between two temporal phases of episodic recollection: an early *access phase* and a later *elaboration phase* (Conway et al., 2001; Conway et al., 2003). The early access phase is dedicated to searching for and selecting the target event (i.e., memories about the recalled episode). To illustrate what goes on during the access phase and why it is important, observe what happens in your mind when you sincerely answer the following question: “How did you celebrate New Year’s Eve last year?” Looking for a memory requires an active, controlled search, and an iterative process of reconstruction (Conway & Pleydell-Pearce, 2000). It involves *cue specification*, a *pre-retrieval* process where humans think about what they are trying to remember (Henson et al., 1999). This allows choosing specific memory cues to guide and refine their search for the correct episode (Bastin et al., 2019). According to the *constructivist model* (Conway & Pleydell-Pearce, 2000), strategic retrieval from autobiographical memory is a reconstruction process following a funnel strategy through three nested types of representations from the most general to the most specific representation (Conway, 2001). At the general level, *lifetime periods* represent periods of several years and are usually defined by a theme such as work, relationships, school, and so on. *General events* include repeated (e.g., weekly yoga sessions) and time-spanning (e.g., my holiday in Thailand) events. Finally, the most specific level is *event-specific knowledge*, which corresponds to the phenomenological register of memories: unique episodes with sensory-perceptual features, often visual images (Conway, 2001). The access phase ends with the selection of the relevant specific event and the simultaneous inhibition of other, similar memories (e.g., New Year’s Eve parties from other years) (Cabeza & St Jacques, 2007). This selection emerges from the interaction between the memory cue and information stored in autobiographical memory (Cabeza & Moscovitch, 2013; Moscovitch, 1995). A successful interaction is associated with *ecphory,* defined as the awakening of a memory trace from a latent state (Frankland et al., 2019; Semon, 1921). Ecphory modifies the consciousness that humans have of their state, as it makes them highly conscious of the fact that they are currently remembering (Tulving, 1976). If the retrieved memory corresponds to the searched one, it generates an intuitive *feeling of rightness* (Moscovitch & Winocur, 2002). Post-retrieval monitoring processes then assess whether the retrieved event is correct and accurate, and verify its veracity further (Gilboa, 2004). If the event is incomplete or incorrect, additional cues are required and the search processes are repeated (Henson et al., 1999). Finally, the internal representation of the memory is explored through mental imagery processes (Rubin, 2006; Sheldon et al., 2019). The event can be mentally re-experienced or relived with various perceptual, emotional, and contextual details (Conway, 2009). Breeden et al. (2016) proposed the existence of a component called the *mental time travel platform*, defined as the temporary internal mental world in which episodic memories can be mentally relived.

The present review aims to focus on the early access phase of strategic autobiographical memory retrieval. As already mentioned, episodic memory retrieval begins with an interaction between a memory cue and an autobiographical past event stored in memory. In daily life, almost all the stimuli that humans encounter can potentially trigger memories. Nevertheless, despite this incredible number of memory cues, humans do not spend their entire time reminiscing. According to Tulving (1988), episodic memory retrieval therefore also requires a specific mental state called *episodic retrieval mode*, namely a tonically maintained mental state oriented toward retrieval (Rugg and Wilding, 2000). Stimuli are therefore only regarded as memory cues when people are in this retrieval mode (Herron & Evans, 2018) allowing them to access internal mental representations during memory retrieval (Küper, 2018; Tarder-Stoll et al., 2020; Xia & Evans, 2020). Tarder-Stoll et al. (2020) suggest that the retrieval mode reflects an intention to remember. It maintains the goal of memory retrieval in mind, which requires attention to be focused on the internal representation of the memory. Once activated, the retrieval mode is thought to last until the end of the memory retrieval period (Rugg & Wilding, 2000).

From this brief overview, we can see that autobiographical memory retrieval involves a complex and highly dynamic cascade of cognitive processes. We now turn to the role of attention in this cascade.

3. Attention to Memory

3.1. Role of attention in memory retrieval

Autobiographical memory retrieval requires the selection of the relevant event in memory. *Selective attention* is therefore needed (Long et al., 2018). The internal attention devoted to episodic memory retrieval is widely referred to as *reflective attention* (Chun & Johnson, 2011). The *attention to memory* model (AtoM; Cabeza et al., 2008; Ciaramelli et al., 2008) has already established that attention plays a crucial role in memory retrieval. According to the AtoM theory, both top-down and bottom-up attentional processes can contribute to episodic memory retrieval. *Top-down* attention is directed by cognitive processes (e.g., expectations or goals) and is largely involved in strategic retrieval while *bottom-up* attention is directed by sensory stimulations (e.g., environmental memory cues) (Cabeza et al., 2008; Ciaramelli et al., 2008; Corbetta & Shulman, 2002) and is involved in associative retrieval (Moscovitch & Winocur, 2002). The major contribution of the AtoM model is the demonstration of the involvement of the posterior parietal cortex, a region well-known for its role in attentional processes, in memory retrieval (Ciaramelli et al., 2008). More specifically, strategic retrieval is associated with activation in the dorsal parietal cortex (Ciaramelli et al., 2008), and the model suggests that this activity is similar during memory and perception (Cabeza et al., 2011). It is therefore assumed that perception and memory require similar attentional control processes (Cabeza et al., 2011). Nevertheless, the connectivity of the posterior parietal cortex with other brain regions differs between memory and perception – while it is highly connected with visual regions during perception, it is connected to the medial temporal lobe during memory. Our main goal here is to highlight the transition which is necessary to redirect attention from perception to memory. Fig.2. illustrates how this attentional switch can be integrated into the cognitive cascade taking place during memory retrieval.

3.2. Dichotomy between internal and external attention

The famous definition of attention coined by 19th-century thinker William James emphasized the ability to focus on either external objects or internal thoughts: “Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or *trains of thought*.” Similarly, the current taxonomy of attention (Chun et al., 2011) makes a fundamental distinction between *external* and *internal* attentional orientation. *External attention* is directed toward information that comes through the senses (Dixon et al., 2014). It refers to the selection of perceptual information from the environment. By contrast, *internal attention* refers to the selection and modulation of internally generated information (e.g., working memory, episodic and semantic long-term memory) (Chun et al., 2011). On the one side, some tasks require attention to be directed toward the environment (perceptually generated thought), as actions must respect environmental constraints (Glenberg et al., 1998). On the other side, many meaningful cognitive activities, such as memory retrieval, require individuals to disengage from the environment to optimize ongoing internal cognitive functions (Handy & Kam, 2015). Attending to autobiographical memories during retrieval is such a form of internal attention. Internal attention should not be neglected since human beings spend about 50% of their time immersed in their thoughts (Killingsworth & Gilbert, 2010).

Given the limited nature of attentional resources -and of working memory capacity-, it is largely assumed that when internal attention is engaged, external attention is suppressed, and vice versa (Handy & Kam, 2015; see Fig. 1 for an illustration). This is explained because internal and external attentional processes compete for the same resources (Dixon et al., 2014). Consequently, internal and external attention can coexist only when both are spontaneous and do not require voluntary processes. As soon as one of them is voluntary and effortful, it cancels the other one (Dixon et al., 2014). Given that strategic retrieval is voluntary and often effortful, it thus involves internal attention, hence a switch of attention.

Working memory temporarily maintains a limited amount of information in mind to guide ongoing behavior. The perceptual or memory content that enters working memory is controlled by a gating mechanism (Verschooren et al., 2021). Once the relevant information is activated in working memory, the system is closed and shielded from other distractions. As a result, when humans attend to the internal world (e.g., during autobiographical memory retrieval), they may be attentionally blind to the external world (Fernandes & Moscovitch, 2002). In the domain of memory, this has been exemplified by the competition between encoding (external attention) and retrieving (internal attention), which cannot occur simultaneously, leading, when necessary, to rapid switches between encoding new information and retrieving information from memory (Kim, 2015). Although attentional resources may not be the only cause of this competition as suggested by alternative interpretations (Huijbers et al., 2009), this decreased perceptual information processing during internal cognition, is widely referred to as *perceptual decoupling* (Smallwood & Schooler, 2006).

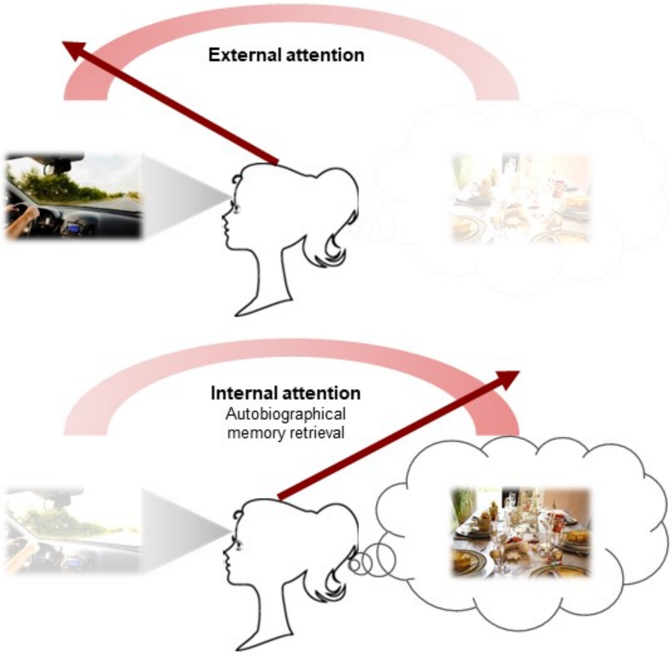

Fig. 1. Illustration of the competition between internal and external attention. Attentional focus cannot be simultaneously directed to internal and external information, resulting in perceptual decoupling when attention is focused on the internal world.

There have been numerous studies of *task switching* (also called *mental flexibility*), a term commonly used to refer to attentional and executive control when switching between two different external tasks (Gilbert & Shallice, 2002; Monsell, 2003), but much less is known about transitions from the external to the internal world (Verschooren, Schindler, et al., 2019). The next section uncovers why attentional switches between the external and internal world cannot simply be considered under the general term of mental flexibility.

3.3. Attentional switch (ASM) between external and internal attention

Weber et al. (1986) were the first authors to look at the daily activities that require an attentional switch between perception (external world) and memory (internal world). They were especially interested in the switch between perception and the maintenance of information in working memory (e.g., following a grocery list at the supermarket) (Weber et al., 1986). The attentional cost of switching between external and internal tasks is asymmetrical, and depends on the direction of the switch: the transition from an external task to an internal one is slower and more expensive than the other way round (Dark, 1990; Verschooren, Liefooghe, et al., 2019, Hautekiet et al., 2022). This can be explained by the fact that residual attention remains directed toward the environment during internal attention, as action must respect environmental constraints to avoid dangerous situations. Consequently, switching attention away from the environment to optimize ongoing internal cognitive functions has a high cost. Conversely, when attention is focused on the internal world, it must switch back quickly to the external environment, in case of danger or unexpected stimulation. Moreover, task-switching tasks have shown that not all internal cognition modes incur the same attentional cost. For example, it appears to be harder to disengage from an episodic task than from a semantic one (Mayr & Kliegl, 2000). Of note, we did not find any study characterizing ASM in the specific case of strategic autobiographical retrieval. Fig. 2 presents a schematic representation of the cognitive processes involved in strategic autobiographical memory retrieval and how ASM relate to them.

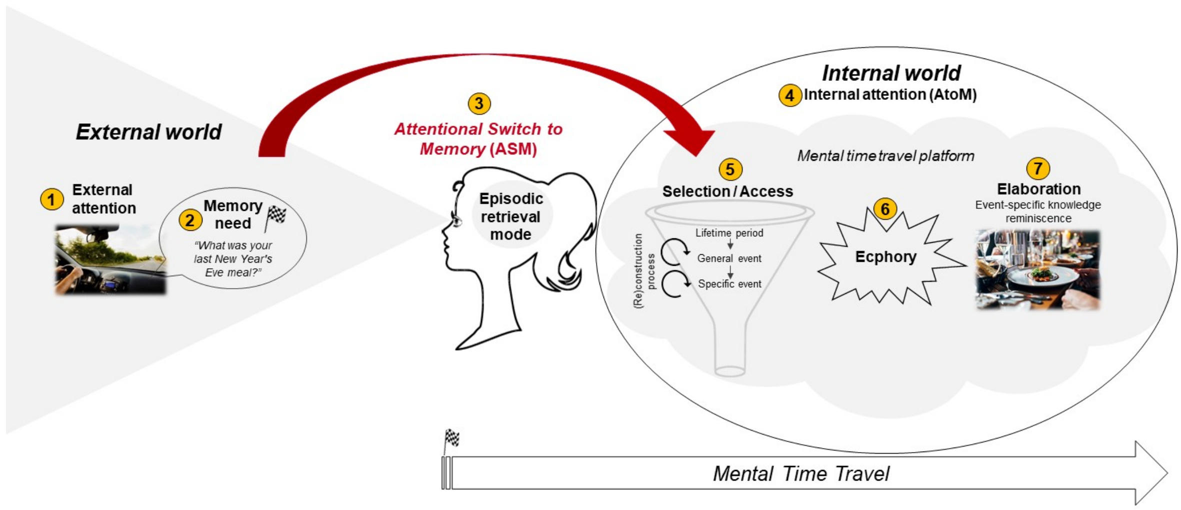

Fig. 2. Schematic representation of the cascade of cognitive operations during autobiographical memory retrieval, incorporating ASM. The yellow circles represent the different phases in a putative chronological order, although there may be considerable overlap between them. The phase shown in red is the hypothesized ASM phase. (1) Some tasks require the attention to be directed toward external stimuli in the environment. In this example, the person is driving and pays attention to the traffic. (2) An element of the environment triggers a memory need (e.g., the passenger asks the driver "How did you celebrate New Year's Eve last year?"). The mental state of the person is oriented

toward retrieval, i.e. episodic retrieval mode. (3) Given the competition between external and internal attention, attention needs to be disengaged from the external environment and switched to an internal mental space. The external world vanishes through perceptual decoupling. This is the phase we have called attentional switch to memory (ASM). (4) Attention is oriented to an internal mental world. (5) Selective attention is then directed toward memories. The selection process requires a controlled active search of the memories stored in autobiographical memory and the inhibition of other, similar, memories. This whole process relies on cue specification and memory search processes. (6) The successful search in memory triggers ecphory (here, awareness of the success of the selection process). (7) During the subsequent elaboration phase, the event can be mentally re-experienced with various perceptual, emotional, and contextual details.

4. Functional brain activity reorganization during ASM

ASM is a critical phase that can change humans' perception of the world in a fraction of a second, by redirecting their attention from the external environment toward memories. We, therefore, hypothesized that the brain undergoes a rapid and major functional reorganization during ASM (Zhou & Lei, 2018). We reviewed different proposals that have been made regarding this switch, noting that many of these are still hypothetical or not necessarily specific to memory retrieval.

Because the ASM has been seldom studied. The hypotheses formulated below are to some extent inspired by the vast and trendy literature about mind-wandering – where the neural correlates and physiological signatures of internal attention have received a lot of interest. Mind-wandering shares similarities with autobiographical memory retrieval: they arise from similar neural substrates (Christoff, Ream, & Gabrieli, 2004), they are both dynamic, associative, and state-dependent (Mildner & Talmir, 2019), they both require mental time travel (Karapanagiotidis, et al., 2017) and interestingly, they both require an attentional switch toward the internal world since mind-wandering is defined as an attentional shift away from events in the external environment toward internal thoughts (Smallwood & Schooler, 2006). Therefore, some authors consider that there is an overlap between mind-wandering and autobiographical memory retrieval (Mildner & Talmir, 2019). Smallwood et al. (2015) pushed the interpretation further by considering mental travel as a characteristic specific to episodic memory – viewing mind-wandering as a by-product of episodic memory. Given those similarities, we can formulate relevant hypotheses and build a new framework for further investigation of the functioning of the attentional switch from the world to autobiographical memory.

4.1. Two anticorrelated networks involved in internal or external cognition

Many studies have supported the idea that the brain is intrinsically organized in two anticorrelated functional networks: one network exhibiting coherent activation during tasks that require attention to external stimuli, and the other showing coherent activation during internally oriented cognition (Fornito et al., 2012; Fox et al., 2005; Vanhaudenhuyse et al., 2011; Zabelina & Andrews-Hanna, 2016). Internal cognition, including successful episodic retrieval from autobiographical memory (Bastin, 2018), is generally associated with activation of the *default mode network* (DMN) (Fox et al., 2015; Mason et al., 2007; Smallwood et al., 2013). The DMN comprises a distributed set of associative cortices, including the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), retrosplenial cortex, inferior parietal lobule, temporoparietal junction, and hippocampal formation (Buckner et al., 2008; Dixon et al., 2014). By contrast, it does not involve the sensory and motor cortices (Margulies et al., 2016; Murphy et al., 2018). Distinct components of the DMN contribute differently to internal cognition, depending on its content. As a result, the DMN is viewed not as a single functional network, but rather as a set of subnetworks (Buckner & DiNicola, 2019). More specifically, the DMN can be divided into two main subsystems that are distinct from the core system (DMN_{CORE}) composed of the anterior medial prefrontal cortex (aMPFC) and PCC (Andrews-Hanna et al., 2010): (1) the *dorsal medial prefrontal cortex subsystem* (DMN_{PFC}) including the dorsal medial prefrontal cortex (dMPFC), temporoparietal junction, lateral temporal cortex, and temporal pole; and (2) the *medial temporal lobe (MTL) subsystem* (DMN_{MTL}) including the ventral medial prefrontal cortex (vMPFC), posterior inferior parietal lobule, retrosplenial cortex, parahippocampal cortex and hippocampal formation. Whereas the DMN_{PFC} is mainly involved in theory of mind and mental simulations, autobiographical memory retrieval relies on the activity of the DMN_{MTL}.

By contrast, external cognition is supported by the *dorsal attention network* (DAN) including the frontal eye fields, superior parietal lobule, and inferior parietal sulcus (Corbetta & Shulman, 2002). The DAN is closely related to visual and somatomotor networks respectively subtending perception and action (Dixon et al., 2014; Zabelina & Andrews-Hanna, 2016). As the DMN and the DAN are mutually exclusive (Fox et al., 2005), they cannot be activated simultaneously, thereby favoring perceptual decoupling (Sestieri et al., 2010; Smallwood et al., 2013).

4.2. How does the brain switch between external and internal attention?

For an effective alternation between introspection and behavior directed toward the environment, the brain must frequently switch between these two states, which correspond to different information processing modes (Tang et al., 2012). However, the mechanisms by which these networks interact and are ordered to switch from one to another remain largely unknown (Buckner & DiNicola, 2019). Hypothesizing that the brain undergoes a rapid, major, functional reorganization during ASM (Zhou & Lei, 2018), we review three proposals concerning the regions that might be involved in this reorganization. As these proposals were not mutually exclusive, we combined them to afford a more complete understanding of the dynamics taking place (see Fig. 3 for one such proposal).

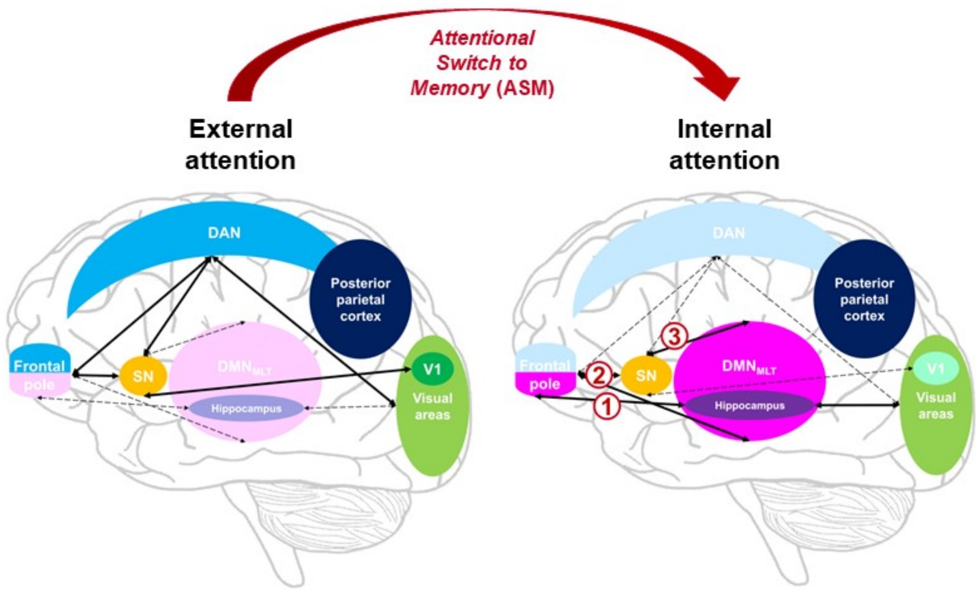

Fig. 3. Hypothetical illustration of the functional brain reorganization that takes place during ASM. Dotted arrows: decreasing connection during ASM. Solid arrows: increasing connection during ASM. Lighter color: decreasing activation of brain regions/networks. Darker color: increasing activation of brain regions/networks. The digits represent the putative chronological order of the dynamic reorganization. The locations where the arrows reach a network are chosen for clarity, and not to highlight any specific region of this network. DAN: dorsal attentional network; DMN_{MTL}: medial temporal subnetwork of the default mode network; SN: salience network; V1: primary visual cortex.

The first proposal involves the hippocampus in the switch between external and internal worlds (Barbeau et al., 2017; Karapanagiotidis et al., 2017; McCormick et al., 2015; Treder et al., 2021) and more precisely the anterior hippocampus (Zeidman & Maguire, 2016), which is connected to the lateral rostral PFC, a structure involved in the early construction stage of autobiographical memory retrieval (Inman et al., 2018; McCormick et al., 2015). The hippocampus is activated early on, during the generation of spontaneous thought (Ellamil et al., 2016), and intracranial electroencephalographic (EEG) data have shown a neural response in the MTL several seconds before spontaneous episodic memory retrieval (Burke et al., 2014). Recent intracerebral recordings in humans have revealed that the hippocampus participates in the transitions between memory (i.e., internal attention) and attentional processes directed toward external stimuli (i.e., external attention) (Barbeau et al., 2017). That's what the HERNET model (Kim, 2015) postulates: switches between encoding (external attention) and retrieval (internal attention) are underlined by the anterior-posterior gradient of the hippocampus – the anterior hippocampus is linked to the DAN while the posterior hippocampus is linked to the DMN (Kim, 2015). Internal and external attention activate different hippocampal subfields: CA1 receives external sensory information through the monosynaptic pathway, while CA3 and the trisynaptic pathway are involved in memory retrieval (Tarder-Stoll et al., 2020).

According to the second proposal, a *supervisory attentional gateway* manages the coordination between external and internal attention (Burgess et al., 2007), namely, the switch of attentional focus from environmental stimuli to internal mental life, or vice versa. The lateral rostral PFC, part of the *frontoparietal network* (FPN) (Kim, 2018), plays a crucial role in the supervisory attentional gateway

(Burgess et al., 2007; Gilbert et al., 2005). Although the internal and external cognition modes activate distinct neural networks (i.e., DMN and DAN), the lateral rostral PFC is part of both (Christoff et al., 2016; Dixon et al., 2014; Fox et al., 2015; Kam et al., 2018). This structure is also involved in both external and internal attention, including episodic autobiographical memory retrieval (Cabeza & St Jacques, 2007; Shapira-Lichter et al., 2013; Svoboda et al., 2006). The FPN is functionally connected to both the DAN and the DMN. It is assumed to allow for a flexible and rapid switch between the two anticorrelated networks (Greenwood et al., 2018). The lateral rostral PFC is largely involved in executive control, which is available in a limited capacity. Hence, internal cognition competes with external cognition because they both recruit the capacity-limited processes of the lateral rostral PFC (Brincat & Miller, 2016; Dixon et al., 2014).

According to the third proposal, the right fronto-insular cortex also plays a critical role in switching between distinct brain states (Tang et al., 2012), particularly between the DAN and the DMN (Goulden et al., 2014; Sridharan et al., 2008). This structure belongs to the *salience network* (SN), an essential interface for proper switching to take place between external and internal worlds (Shaw et al., 2021; Zabelina & Andrews-Hanna, 2016). The SN is composed of the anterior insula and anterior cingulate cortex (Menon & Uddin, 2010). Like the FPN, it is regarded as an important brain hub, enabling transitions between external and internal attentional networks (Zabelina & Andrews-Hanna, 2016). According to Christoff et al. (2016), the transitions between these brain states depend on different constraints. First, the SN exerts continuous automatic control over the FPN, DAN (which influences activity in sensorimotor areas), and DMN_{CORE} (which influences activity in DMN_{MTL}). Second, the FPN can in turn exert constraints on the DAN, SN, and DMN_{CORE}, depending on the current cognitive task. Finally, sensorimotor areas and the DMN_{MTL} can modulate activity in the SN, depending on the relevance of the information (i.e., external or internal). It is therefore essential to understand the functional dynamics between these different networks (DMN, FPN, and SN), in order to understand the brain dynamics that take place during ASM. Functional connectivity analyses have revealed that different brain states occur during different tasks. During periods of rest, which are conducive to the emergence of spontaneous thoughts, there is negative connectivity between the SN and FPN, as well as between the DMN and SN, whereas the connectivity between the DMN (especially in the PCC) and FPN is positive (Denkova et al., 2019). By contrast, during an external attentional task, the DMN (especially the medial PFC) shows negative connectivity with the SN and FPN, whereas there is positive connectivity between the SN and FPN (Denkova et al., 2019). There is also negative connectivity between the FPN and DMN (Denkova et al., 2019). In summary, the SN seems to interact with the FPN and DMN, allowing switches to take place.

Albeit tentative, we can see from this short review that several large-scale networks and brain areas are probably involved in ASM, although it is as yet unclear which aspects are specific to autobiographical memory. The brain dynamics that take place during ASM therefore need to be clarified. As an attempt to provide a framework specific to autobiographical memory, we propose the hypothetical model depicted in Fig. 3. Because the hippocampus seems activated early even before the emergence of internal thoughts (Burke et al., 2014; Ellamil et al., 2016; Rubin, 2006), we believe that it plays a role in the initiation of the switch. Then, since the hippocampus is strongly connected to the aLPFC during the early access memory phase (McCormick et al., 2015; Inman et al., 2018), if the hippocampus activity signals a retrieval attempt (activation in CA3, Tarder-stoll et al., 2020), the aLPFC could act as a "*supervisory attentional gateway*" (Burgess et al., 2007) to deactivate the DAN and activate the DMN (Dixon et al., 2014) through modulation by the SN (Chirstoff et al., 2016; Tang et al., 2012).

4.3. Impact of perceptual decoupling on visual cortex

Patients with lesions in visual regions experience autobiographical memory impairments (e.g., patients with visual memory-deficit amnesia) (Rubin & Greenberg, 1998). At the other extreme, a case study of highly superior autobiographical memory reported very high levels of activation in posterior visual areas such as the precuneus during autobiographical memory retrieval (Mazzoni et al., 2019). Such activations in high-level visual areas demonstrate the fundamental role of visual imagery in autobiographical memory retrieval (Cabeza & St Jacques, 2007).

However, although the secondary visual and somatosensory cortices are activated during internal thoughts, the primary sensory cortices are not activated (Chun et al., 2011; Fox et al., 2015; Wheeler et al., 2000). More specifically, reduced visual processing has been observed in low-level visual areas during internal cognition (Chun et al., 2011; Gorgolewski et al., 2014; Smallwood et al., 2008). ASM may be accompanied by an early deactivation of primary visual areas supporting visual decoupling. The early access phase is associated with deactivation of visual areas, while the elaboration phase is associated with activation of associative visual areas (Inman et al., 2018). Associative visual areas such as the precuneus, retrosplenial cortex, and lateral occipital regions exhibit increased activity during autobiographical memory retrieval (Bréchet et al., 2019; Chun et al., 2011; Conway et al., 2001; Fox et al., 2015; Inman et al., 2018; Wheeler et al., 2000), and may be involved in the mental imagery needed to facilitate retrieval (Cabeza & St Jacques, 2007). Consequently, if secondary visual areas are involved in visual mental imagery during memory retrieval, they, like the primary visual cortices, may not be able to simultaneously process external visual stimuli from the environment (Johnson & Johnson, 2014), thus reinforcing the perceptual decoupling.

5. Gaze aversion as an objective behavioral signature of ASM

In this section we suggest that eye movements are potential objective signatures of ASM and we highlight in Box 1 why such an objective marker is important for different fields of research.

Eye movements seem crucial for good autobiographical memory retrieval, as preventing people from moving their gaze (by asking them to fixate a dot) reduces the quality of their mental imagery and the number of details it contains, compared with a free viewing condition (Lenoble et al., 2019). The most well-known theory demonstrating the intimate relation between autobiographical memory retrieval and eye movements is *gaze reinstatement* or the *scan path theory* – during memory retrieval, the gaze reenacts the visual pattern observed during the encoding of the event (for recent studies, see Johansson et al., 2022.; Wynn et al., 2019). Other eye behaviors are however observed during autobiographical memory retrieval. One of those is *looking at nothing* – staring at a neutral part of the environment with little visual distractors (Salvi & Bowden, 2016). Visual distractors in the environment can disturb episodic memory retrieval and lead to less precise episodic recollection (Sheldon et al., 2019; Wais et al., 2010). By the same token, a reduction in external visual information substantially improves retrieval from memory (Einstein et al., 2002), even for weakly accessible knowledge (Radel & Fournier, 2017). Consequently, some studies have identified oculomotor behavior that appears to be aimed at reducing visual input during autobiographical memory retrieval. For example, witnesses usually recall more details when their eyes are closed (Perfect et al., 2008; Vredeveldt et al., 2015), probably owing to enhanced mental visualization (Vredeveldt et al., 2011).

Nevertheless, in daily life, it is quite rare to see people closing their eyes while remembering. Instead, *gaze aversion* is frequently encountered in everyday situations. It may even have happened to you when you were trying to answer the earlier question about your New Year's Eve party. Glenberg et al. (1998) showed that people trying to answer difficult memory questions tend to shift their gaze away from their interlocutor and naturally avert their gaze. They give the impression of searching for the answer on the ceiling or *in the sky* (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998), which is compatible with the "looking at nothing" phenomenon where people prefer looking at neutral parts of the space such as blank walls while retrieving (Salvi & Bowden, 2016). Gaze aversion may play a functional role in memory retrieval, as performance is better when people avert their gaze (Glenberg et al., 1998). The *cognitive load hypothesis of gaze aversion* (Abeles & Yuval-Greenberg, 2017) suggests that averting the gaze from external distractors in the surrounding environment optimizes performance on tasks requiring internal attention (e.g., autobiographical memory retrieval). Therefore, gaze aversion can be regarded as a strategy that supports perceptual decoupling. It may allow individuals to disengage from the current spatial and temporal context, in order to concentrate on past mental images.

Interestingly, when the gaze is averted to reduce the influence of external distractors and facilitate ongoing internal thoughts, it is preferentially directed upward (Andrist et al., 2014). However, we do not currently have a proper scientific explanation as to why the upward direction is preferred during internal attention other than a ceiling or the sky is a relatively neutral visual stimulus, with few distracting details.

Gaze aversion can last for several seconds, on average 3.54 ± 1.26 seconds (Andrist et al., 2014) during conversations for example. It should be noted that such behavior may be correctly interpreted by a viewer. When a person is looking upwards and sideways at a location with no meaningful object, for example, children can infer that the person is thinking (i.e., internal attention) (Baron-Cohen & Cross, 1992). Gaze aversion may therefore also allow other people's mental states to be inferred. If this is the case, it confirms that gaze aversion occurs regularly enough to have become a social marker of a specific cognitive state. As gaze aversion is related to cognitive effort (Glenberg et al., 1998) and starts early during the early access phase, the moment at which gaze aversion begins presumably signals the attentional switch toward memories, which initiates strategic autobiographical retrieval. Directing the gaze toward a neutral part of the space may allow attentional resources to be focused on the mental time travel platform (i.e., temporary internal mental space), in order to search for information in memory and maintain this information in a representational space (internal attention). Keeping the gaze away from distractions could indicate that the person is mentally exploring the representation, visualizing the scene, and reliving the event. Gaze reinstatement in contrast is closely linked to mental imagery and is supposed to occur during the elaboration phase to allow the mental exploration of the scene (Bone et al., 2019; Daselaar et al., 2008). How both gaze aversion and gaze reinstatement relate is an interesting topic for future studies.

Given that gaze aversion during autobiographical memory retrieval seems such an ecological, easy-to-study, and common behavior, we were surprised to find such a dearth of relevant scientific literature. It is worth studying gaze aversion as a marker of internal cognition, as the other eye behaviors that have been reported during internal cognition cannot be detected at a single-trial level in real time. For example, higher eye blink frequency during internal versus external cognition is an indicator based on an a posteriori mean (Benedek et al., 2017). Blinking per se does not indicate a switch toward the internal world. By contrast, gaze aversion could be an *objective* and *temporally* accurate marker of engagement in autobiographical retrieval, potentially allowing researchers to detect in real-time attentional switch between internal and external worlds.

Cognitively, gaze aversion is hypothesized to favor perceptual decoupling. This could occur at two different levels. The first mechanism, which has already been proposed by Glenberg et al. (1998)

and the *looking at nothing* hypothesis (Salvi & Bowden, 2016), consists in directing the gaze toward the floor, ceiling, or sky – i.e., neutral and uniform surface containing far fewer visual distractors than the rest of the surrounding environment. The second possible mechanism is based on the characteristics of the oculomotor system. The eyes have a limited range of movement, of around 50° from the central primary position (i.e., looking straight ahead), and at far eccentricities (greater than approximately 20°), the eye position becomes less stable, leading to less precise vision (Nakashima & Shioiri, 2014). Consequently, to visually explore the environment – a situation requiring optimal visual processing – the head rotates for gaze changes greater than 20° (Land & Tatler, 2009) – allowing to compensate for this anatomical limitation. By contrast, we hypothesize that the head does not follow the direction of the eyes during gaze aversion. Although gaze aversion brings the gaze at far eccentricity, the head would not follow the eyes to favor perceptual decoupling. In this situation where attention must be directed toward internal memories, taking advantage of this anatomical limitation is beneficial to reducing the visual processing of potential external distractors. Internal and external attentional states could therefore be differentiated according to the match or mismatch between the direction of the eyes and the direction of the head (see Fig. 4 for an illustration).

Note that we exclusively focus on eye movements in this section and decide to not tackle other potential markers of ASM. Nevertheless, as explained earlier, ASM is presumably accompanied by a massive modification in brain activity, raising the possibility that ASM has also an EEG signature. This, along with eye movement monitoring, could also be a powerful and measurable temporal marker of autobiographical memory retrieval.

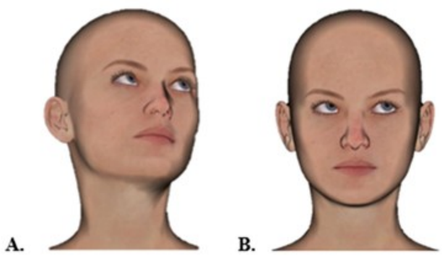

Fig. 4. A) An illustration of a gaze that we assume to be related to external attention (selective): the head congruently rotates in the same direction as the eyes. B) An illustration of an

averted gaze that is assumed to be related to a cognitive state requiring internal attention (e.g., autobiographical memory retrieval): during the eye movement, the head remains still or moves in a different direction. (Images created with the open-source software DAZ Studio 4.12, www.daz3d.com)

Box 1. Applications of ASM

We hypothesized that ASM has observable and measurable oculomotor signatures. This is critical since detectable markers of ASM could be extremely valuable in various fields, as we briefly set out below.

1. Neuropsychology: investigating amnesia

One application of ASM markers would, of course, be to assess whether failure to perform ASM can contribute to amnesia or other cognitive dysfunctions (e.g., if part of the network needed for ASM is damaged). Patients with memory impairment stemming from frontal lesions have difficulty accessing memories (Wheeler et al., 1995). They also have difficulty disengaging their attention from the external environment, and exhibit dependence on the latter (O'Callaghan et al., 2019). We can hypothesize that the attention they direct toward their internal world is not sufficient to retrieve memories, owing to a disturbance of ASM. By contrast, after a traumatic event, patients with posttraumatic stress disorder experience intrusive memories (Berntsen, 2010) that could also be due to a dysfunction of the system supporting ASM. Other patients present spontaneous confabulations in the form of stories dominated by autobiographical experiences and contaminated by imaginary elements (Schnider, 2003). Spontaneous confabulations reflect deep confusion between ongoing reality (external world) and past memories (internal world), owing to a failure to suppress the activation of past episodic memories. A disturbance of ASM, which is also a gating mechanism to avoid confusion between the external and internal worlds, could generate inappropriate switches. These hypotheses require confirmation, but open up a new avenue of research in neuropsychology.

2. Research in neurosciences: an objective, temporal marker of autobiographical memory retrieval

If researchers found a specific temporal oculomotor marker of autobiographical memory retrieval, it could be highly useful in EEG and functional brain imaging studies investigating the neural correlates of autobiographical memory. This marker would provide an objective measure of whether the participant was actually engaging in remembering (Conti & Irish, 2021). Experimenters generally use lengthy subjective self-report to ensure that participants engaged in autobiographical memory retrieval. An objective temporal marker would allow skipping this fastidious step. In addition, the oculomotor activity could be used as a temporal marker to precisely track brain activity—something that is currently impossible with oral interviews. Retrieval trials could thus be temporally aligned before averaging, thus increasing the power of the analyses.

3. Social cognition: gaze aversion as a social cue

ASM is accompanied by gaze aversion (Glenberg et al., 1998). The latter may play a role in social interactions, as the gaze is a powerful social cue that allows us to decode others' mental states (Baron-Cohen et al., 2001). During social interactions, there is generally eye or eye-to-face contact (Pasupathi, 2001; Turkstra, 2005), and a listener's gaze tends to follow the gaze direction of the speaker so that their attention is directed toward the same external information (Droulers & Adil, 2015; Koike et al., 2016; Nummenmaa & Calder, 2009), in a form of joint attention (Emery, 2000; Frischen et al., 2007). One question that remains to be investigated is whether gaze aversion and which of its characteristics, can be interpreted by a viewer as a sign that the speaker is focusing on personal memories, rather than on an external stimulus.

4. Comparative psychology

The existence of episodic memory and mental time travel in nonhuman species is still a subject of hot debate (Crystal & Suddendorf, 2019). In humans, language allows for easy communication about past events, but it is of course difficult to investigate this ability in other species. An objective marker that would be specific to ASM, but common across species, even in a prototypical form, could be highly useful for assessing whether nonhumans can switch to an internal world.

6. Limitations

In this review, we focused on ASM, an early component of the cascade of processes involved in memory retrieval that has been largely ignored, despite its presumably critical role. Most of what we were able to infer about ASM was derived from studies that were not specific to autobiographical memories, but more generally related to the switch from external to internal cognition or from related fields such as mind wandering. This was notably the case for the brain reorganization that is hypothesized to take place during ASM. It therefore still has to be clarified whether there is anything specific to autobiographical memory in ASM.

We focused mainly on strategic, rather than associative, retrieval from autobiographical memory as ASM is then most conspicuous. Strategic retrieval can last for several seconds and can easily be induced in the lab, making it a good candidate for investigation. In this regard, the type of ASM that takes place during associative retrieval has yet to be investigated.

Last, some forms of ASM may take place during retrieval from semantic memory, particularly for difficult questions (e.g., trying to retrieve the name of the capital of Mongolia or the names of British Prime Ministers since World War II), or even during other tasks requiring internal attention, such as future thinking and imagination. There are well-known debates about the specificity of human episodic memory or mental time travel with regard to either other types of memory or nonhuman species. We cannot discuss them here, but it should be noted that studying ASM may be helpful to clarify some aspects of these debates.

7. Conclusion

Our review suggests that ASM is an early and necessary phase of autobiographical memory retrieval. It is fascinating to realize just how critical a moment ASM is in humans' cognitive lives, changing their perception of the world in a fraction of a second. It allows them to divert their attention from the external world to focus on the internal world containing memories and thoughts. Despite its importance in everyday life, our review also highlights how little we know about ASM and calls for future research on this promising topic.

Declarations

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- Conflict of interest/Competing interests

The authors do not have any competing interests to declare.

- Ethics approval

This is a theoretical paper. No ethical approval is required.

- Consent to participate

Not applicable

- Consent for publication

Not applicable

- Availability of data and materials

Not applicable

- Code availability

Not applicable

Open Practices Statement

This paper is a theoretical review. Preregistration, as well as data and code sharing, are therefore not applicable.

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