Trends in Cognitive Sciences

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Opinion

Individual Differences in Autobiographical Memory

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Although humans have a remarkable capacity to recall a wealth of detail from the past, there are marked interindividual differences in the quantity and quality of our mnemonic experiences. Such differences in autobiographical memory may appear self-evident, yet there has been little research on this topic. In this review, we synthesize an emerging body of research regarding individual differences in autobiographical memory. We focus on two syndromes that fall at the extremes of the 'remembering' dimension: highly superior autobiographical memory (HSAM) and severely deficient autobiographical memory (SDAM). We also discuss findings from research on less extreme individual differences in autobiographical memory. This avenue of research is pivotal for a full description of the behavioral and neural substrates of autobiographical memory.

Highlights

The syndromes of highly superior autobiographical memory (HSAM) and severely deficient autobiographical memory (SDAM) have come under recent investigation. These syndromes pose challenges for theories of memory.

Research on individual differences in autobiographical memory across the spectrum have also emerged, complementing prior work involving individual differences in laboratory-based episodic memory.

Additional research that is focused on HSAM and SDAM, particularly those involving larger sample sizes, will provide a novel platform for understanding the cognitive and neural factors that are associated with the formation and retention of autobiographical memories.

Individual Differences in Remembering

Humans are capable of retaining a wealth of detail from personal (autobiographical) memories. Yet, the quantity and quality of mnemonic experience differs substantially across individuals. Although these individual differences in autobiographical memory may appear self-evident as in conversations with friends and family, there is little empirical research on this topic. In this paper, we synthesize research concerning individual differences in autobiographical memory capacity with a view towards understanding its origins and functional implications. Here, autobiographical memory is defined as encompassing both the recollection of personal past events as well as factual knowledge about oneself [1,2]. Autobiographical memory performance can be dissociated from performance on laboratory memory tests, both at the behavioral and brain level [3–5]. Our review focuses mainly on two syndromes at the extremes of a remembering dimension: highly superior autobiographical memory (HSAM) and severely deficient autobiographical memory (SDAM). People with HSAM have an uncanny ability to recollect an abundance of detail pertaining to autobiographical experiences [4,6–12]. By contrast, people with SDAM cannot vividly recollect autobiographical experiences [3,13,14], but are otherwise cognitively healthy. In addition to reviewing these extreme cases, we incorporate emergent findings from research on less extreme forms of individual differences in autobiographical memory. Together, this work indicates that the study of individual variability, at the extremes and across the spectrum, provides a new and exciting platform for understanding the behavioral and neural underpinnings of autobiographical memory.

Extreme Cases: Behavioral Presentation

The first modern case of HSAM, Jill Price (also known as 'AJ') was reported in 2006 [10]. She could recall many if not most days of her life from about age 11, including both personal happenings and public events. This memory 'syndrome' was dubbed hyperthymestic syndrome ('excessive remembering') but is now referred to simply as HSAM. (After the 2006 publication, a relatively obscure case report from 1871 was discovered in which Daniel

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McCartney, a 54 year old male, was noted to report, for any date from age 11, the day of the week, the weather, news events, and personal happenings [15]; also see [6,16].) Following the publication on Jill Price and subsequent publicity, a group of people with HSAM were identified and described in detail by researchers at UC Irvine [8]. Using stringent measures for dating personal and public events (e.g., When did Jimmy Carter win the Nobel Peace prize?), the authors identified 30–40 people with verifiable HSAM; 11 of these participated in follow-up assessment (more have since been identified, although the number remains fewer than 100 [16]). Notably, the majority who claimed to have HSAM failed to meet the criteria for this syndrome, with some performing below expectation on the given measures [8]. While this finding may be attributable to the stringent nature of the screening materials used to assess HSAM, another possibility is that it pertains to differences between actual autobiographical memory performance and metacognitive awareness (i.e., self-report).

The remarkable performance of HSAM individuals on these screening measures is not paralleled by performance on standard cognitive tests. That is, people with HSAM do not excel on neuropsychological tests administered in the laboratory [4,8,11,12], with the exception of some standard neuropsychological tasks of memory [4,7,8]. The advantage observed on these neuropsychological memory tasks is unmatched to their superiority for personal and public event recall.

To determine if HSAM individuals use specialized processes when remembering autobiographical events, one study tested susceptibility to false memory distortions, a marker of reconstructive remembering. Remarkably, people with HSAM were no less prone to memory distortions than those without HSAM [7]. Thus, to the extent that memory distortions for laboratory material reflect reconstructive processes, it appears that these processes cannot account for HSAM. One might speculate that HSAM can be accounted for by rote memorization. This does not appear to be the case, as illustrated by the fact that HSAM individuals excel on recall of events that were unlikely to have been rehearsed (e.g., events that occurred on 24 successive Easter holidays in a person who is Jewish [10], the date that Jimmy Carter won the Nobel Peace Prize, or the weather conditions on one's 18th birthday [8]). Whereas some individuals with HSAM keep detailed journals, others do not. In this respect, people with HSAM are different from mnemonists or memory athletes (i.e., people that deliberately memorize large amounts of meaningless or trivial information using mnemonic aids and tricks) (see [17], also see [12]).

At the other extreme are those with SDAM [3,13,14]. These are individuals who are unable to vividly recollect autobiographical experiences from their past, in the absence of detectable neural pathology or deficits in functional living. Like HSAM, SDAM individuals show normal performance on neuropsychological tests of attention, perception, working memory, and executive function. They also demonstrate preservation in the ability to learn and retain factual (i.e., semantic) information; their deficit is specific to measures of autobiographical memory. Critically, formal memory testing indicated a modality-specific deficit on visual memory tasks in SDAM; there was no evidence of impairment for verbal memory [3], suggesting that spared verbal-semantic mnemonic processes mediate their intact performance on laboratory and real life memory tasks.

To date, only five of such individuals have been systematically investigated [3,13,18], three of which have been studied in our laboratory [3,13]. As described in more detail later, two other cases self-reported a lifelong absence of visual imagery with a concomitant impoverished sense of reliving of autobiographical memories that is akin to SDAM ([18] also see [19,20],

discussed below). The absence of visual imagery has since been dubbed aphantasia. Deficits in autobiographical memory (potentially SDAM) are likewise common in such individuals, with over 20 cases reported and many more claiming to have aphantasia in response to media reports [20]. Similarly, media reports following our publication on SDAM [3] elicited many hundreds of individuals claiming to have SDAM who have contacted our laboratory (B.L.) for participation in research, though many such individuals may not have SDAM (as was the case for HSAM).

Unlike HSAM, a superior capacity that can be verified through the presence of responses to detailed questions about events, SDAM (like aphantasia and other developmental deficiencies [21–23]) cannot be definitively confirmed as it is characterized by a deficient or absent ability. The primary inclusionary criterion is chronically low self-reported episodic autobiographical memory [which can be assessed with the Survey of Autobiographical Memory (SAM)] [24,25] (Box 1). Formal testing of autobiographical memory for events may or may not show impairments, depending on the method and time period assessed, as it is possible for people with SDAM to recall 'episodic-like' details in the absence of re-experiencing (Boxes 1 and 2) (SDAM cases have shown greater impairment for remote than recent time periods). As discussed in detail below, individuals with SDAM failed to engage the brain's autobiographical memory network when stimulated with personalized autobiographical cues. Such cues robustly activate this network in other healthy adults [3], and such an approach is not as prone to demand characteristics or biases as purely behavioral methods. Although SDAM is considered to be a developmental condition, it may not be recognized until early adulthood, as with other developmental conditions [19,21,22]. Acute or late onset memory changes, including those associated with post-traumatic stress disorder (PTSD) and depression, are not part of the syndrome. SDAM is selective and specific to autobiographical memory. Individuals with SDAM should therefore not have other significant cognitive impairments, although associated deficits (such as imagery) may be present. The cause of SDAM is unknown, but any neurological condition known to cause memory impairment (e.g., epilepsy, developmental amnesia) is exclusionary.

Box 1. Assessing and Manipulating Autobiographical Memory

The Autobiographical Memory Interview (AMI) [120] provides indices of episodic and semantic memory on the basis of examiner ratings of responses to questions about specific defined events and facts. The TEMPau task [121,122] adopts a similar structured interview approach for events with a greater range of ratings for episodes (non-episodic memory is not assessed). In the Autobiographical Interview (AI) [123], events are selected and freely recalled by the participant (within constraints defined by the experimenter). The transcribed protocol is then segmented into internal or episodic (event-specific) and non-episodic (e.g., semantic or factual statements) categories. These features enhance flexibility and range in quantification of elements of autobiographical memory, resulting in wide application in patient and healthy samples, particularly with respect to individual differences (Figure 1). The Survey of Autobiographical Memory (SAM) measures aspects of autobiographical memory, via self-report, at the 'trait' level (i.e., how good or poor one's memory is in general) and includes episodic, semantic, spatial, and future subcategories [25]. We and others have used the SAM recently to examine individual differences, and to explore conditions in which episodic and non-episodic components of autobiographical memory dissociate (see e.g., [24,124]; Figure 1).

As these approaches rely on retrospection, they afford little experimenter control. Researchers have recently turned to staged events that offer control over the event content for subsequent testing (e.g., see [4,117–119], also see [93]). Wearable cameras afford similar benefits [125].

Beyond measurement, recent work has focused on modifying autobiographical memories. For example, episodic aspects of autobiographical memory can be modified at retrieval [119,126–128]. A brief induction session that promotes the use of episodic memory processes can affect the quality of episodic recall (typically measured with the AI; see [129]). This episodic induction technique also enhances performance on a number of autobiographical-related tasks, from problem solving to creativity [41,130]. Such findings raise questions about how this modification of retrieval interacts with trait-level approaches to autobiographical memory retrieval (e.g., SAM scores). That is, are some individuals more prone to demonstrate memory modification effects?

Box 2. Encoding versus Post-encoding Alterations in HSAM and SDAM

To explicate the mechanisms underlying HSAM and SDAM, researchers have begun to explore whether memory differences in these syndromes are due to altered encoding versus post-encoding processes. In other words, do these syndromes reflect differences in the way memory traces are initially formed, or do they reflect alterations in the retention or recovery (retrieval) of these memory traces? Notwithstanding difficulty in teasing these aspects of memory apart, this work has largely involved comparing mnemonic performance across different retention intervals (i.e., time periods). For example HSAM participants did not differ from comparison participants in the quantity of recollected episodic details (as measured by the number of internal details recalled using the AI) from the most recent time period (1 week) but showed a more shallow forgetting-curve relative to controls for subsequent time periods (see also [4]). These results suggest that HSAM may be best accounted for by altered post-encoding processes related to either memory retention or retrieval. Put more concretely, it is possible that normal forgetting is attenuated in people with HSAM. Alternatively, it is possible that individuals with HSAM have superior encoding processes and that retrieval assessment is insensitive to differences at early test intervals due to ceiling effects. In either case, the fact that these effects are only evident after a delay may partly explain why mnemonic differences are not typically observed on laboratory tasks of memory in HSAM.

We used a very similar approach in SDAM to test memory at different retention intervals, but with a more extended timeframe (1 week, 1 month, 1 year, 10 years, teenage years, childhood). We found that individuals with SDAM differed from matched controls in the quantity of episodic details (i.e., internal details on the AI) for memories recalled from remote time periods only (i.e., teenage years, childhood, [3]). Although these findings also point to post-encoding processes, it is notable that people with SDAM report reduced subjective recollection of experiences (i.e., they rate their memories as less vivid) irrespective of the age of the memory. Moreover, impaired performance on visual episodic memory tasks in SDAM emerged after very short retention intervals [3]. Further, in an immediate test of recognition, SDAM individuals showed attenuation in an ERP index of recollection (although recognition memory performance was not significantly impaired [3]). Considering the AI data, we reasoned that preserved internal detail recall from recent events reflect non-episodic processes (i.e., 'episodic-like' details, as seen in episodic autobiographical amnesic patient M.L. [82]); such details are specific in time and place but lack a phenomenological sense of recollection, an important feature of episodic memory emphasized by Tulving [84]. Together, these findings suggest that SDAM may be due to faulty mechanisms that take place as early as encoding.

Extreme Cases: Neural Correlates

As expected, considering most other developmental syndromes [26,27], there are no focal abnormalities in HSAM and SDAM. Key differences between affected individuals and comparison participants are evident at the network level, as reflected in subtle structural anatomical variation and connectivity differences (see also [28,29], Box 3, and Figure 1). Whole brain MRI and diffusion tensor imaging (DTI) analyses in HSAM show larger (and in some cases smaller) grey and white matter volume in a number of regions, including increased white matter integrity in the parahippocampal gyrus and uncinate fasciculus, as well as decreased grey and white matter integrity in lateral temporal regions. Other areas showed patterns of both increased and decreased structural integrity, including parts of the basal ganglia (caudate and putamen; increased grey but decreased white matter) and the intraparietal sulcus (increased white matter

Box 3. Anatomical Correlates of Individual Differences in Memory

Many studies to date have focused on the anatomical correlates of individual differences in laboratory measures of episodic memory, with a particular emphasis on the hippocampus. Surprisingly, these studies have failed to observe reliable associations between episodic memory performance and hippocampal volume [131]. Yet, overall hippocampal volume may not be a precise enough proxy of neuroanatomical variation, highlighting the importance of examining hippocampal subregions in relation to individual differences in episodic memory [132]. Other work has focused on individual differences in the strength of white matter connections that course through medial temporal lobe structures, demonstrating relationships between individual differences in episodic memory and the integrity of the fornix [133], and the uncinate fasciculus [134]. More recently this work has been extended to autobiographical memory. For example, a recent study has shown a relationship between individual differences in aspects of autobiographical memory retrieval and precuneus [65] and hippocampal subfield volume (Figure 1) ([65,135], also see [136]). It is of great interest to determine whether individual differences in hippocampal subfields are relevant to SDAM and HSAM. Individual differences in episodic autobiographical memory are also associated with white matter integrity of the fornix, whereas variability in semantic autobiographical memory (a subcomponent of external details on the AI) is associated with the inferior longitudinal fasciculus [28] (Figure 1). In aging, the tendency to shift towards a higher proportion of external details in autobiographical recall (as measured with the AI) is associated with increased coupling between default and executive brain networks, as assessed by resting state fMRI [29] (Figure 1).

but decreased grey matter; see [8] for details). In another report of a single individual with HSAM (H.K.), right amygdala hypertrophy was observed, coupled with a general reduction in volume of cortical and subcortical regions, although the fact that this individual is congenitally blind may affect interpretation of these findings [11]. Another individual with HSAM (M.M.) was observed to have a larger right temporal pole and a smaller right perirhinal cortex (and to a lesser extent, left entorhinal cortex) volume relative to comparison participants. Moreover, M.M. showed an atypical deepening of the left collateral sulcus and an anomalous white matter band coursing through left medial temporal cortices [12]. Such anatomical variations distinguish those with HSAM from 'memory athletes', those who are well practiced in mnemonic techniques but show no specific anatomical differences relative to comparison participants [30]. Smaller brain volume may seem counterintuitive in the face of superior memory abilities, yet positive correlations between cognitive performance and brain volume are not consistently observed. Indeed, smaller volumes may reflect tradeoff effects with larger neighboring regions [31], which were not tested. Quantitative MRI work on SDAM has focused on the anatomy of the hippocampus, showing right-lateralized reduced volume of this region relative to comparison participants [3]. Although it is not possible to determine whether the structural differences observed in HSAM and SDAM precede or are a consequence of these syndromes (or whether they are epiphenomenal to their memory alterations), it is notable that the identified structures mirror the autobiographical memory network [32–34], as discussed in more detail below (Box 3).

In terms of functional neuroimaging, in HSAM, increased resting-state hippocampal–amygdalar functional connectivity was reported in the blind individual (H.K.) [11], while decreased hippocampal–medial temporal lobe cortical connectivity and increased hippocampal–cortical connectivity, was reported in M.M. (particularly with lateral frontal regions [12]). As these connectivity effects were observed at a liberal statistical threshold in a single case, they require replication. As noted above, findings in the three reported individuals with SDAM suggest reduced task-based fMRI-related activation in critical nodes of the autobiographical memory network during autobiographical recollection (e.g., medial prefrontal cortex and precuneus [3]) as well as attenuation in an event-related potential (ERP) index of recollection of laboratory materials [3]. Using magnetoencephalography (MEG), a single case of SDAM (S.M.) was found to have reduced gamma synchrony and theta-phase coupling relative to comparison participants during autobiographical recollection [13]. Together, these findings suggest reduced engagement of the canonical autobiographical memory network in SDAM.

How Extreme Cases Can Inform Models of Memory

The presence of individuals who fall at such extreme ends of the spectrum of autobiographical memory ability poses challenges to current theories of memory. Emerging work has indicated that episodic recollection is essential to quality of life, contributing to a host of functions, including future prospection [35–37], decision making ([38]; but see [39]), problem solving [40], creativity [41], or sense of self [42,43]. While these studies highlight the adaptive importance of detailed (i.e., episodic) remembering, it is also recognized that forgetting is a crucial feature of normal memory function [44–46]; it should not be advantageous to have innumerable trivial details available to consciousness [47]. Thus, both extremes should have negative consequences, yet neither SDAM nor HSAM provide obvious support for these ideas (although people with HSAM have shown an elevated rate of obsessive-compulsive traits [8]). While more subtle functional impairments in HSAM or SDAM may be revealed with further study, there is no evidence to date that these individuals' day-to-day function is impaired. Research on functional consequences of memory syndromes typically involves individuals with acquired brain injuries, where adjustment is required to cope with cognitive changes. We suspect the lack of functional

impairment in those with extreme memory abilities on a lifelong basis is due to compensatory strategies engaged throughout development. Thus, an improved understanding of the mechanisms driving these extreme cases, as well as less extreme forms of individual differences in remembering, can specify the particular components of memory that serve adaptive remembering and forgetting functions, a topic we turn to in the next section.

Individual Differences in the Component Processes of Autobiographical Memory

Although the literature on individual differences in autobiographical memory in less extreme forms is limited, a burgeoning literature suggests that such individual differences may manifest at the level of component processes within autobiographical memory. Indeed, autobiographical memory is complex and multifaceted, requiring both domain-general (e.g., search, inhibition, maintenance) and domain-specific processes (e.g., perceptual, self-referential, affective, spatial, temporal, etc.). Below we provide evidence for the importance of some of these domain-specific component processes as mediating individual differences in autobiographical memory; we focus on three possible candidate factors: visual imagery, self-referential processes, and emotion. Further, we discuss how these factors may be relevant to alterations observed in HSAM and SDAM, acknowledging that these ideas are speculative. We review these factors as a means of provoking future research on this topic.

Visual Imagery

There is good evidence that visual imagery influences how autobiographical events are recollected [48]. For example, damage to brain areas implicated in visual imagery negatively impacts autobiographical memory retrieval [49–51]. In addition, enhancing imagery processes, through behavioral training, can improve autobiographical memory recall (e.g., [52]; Box 1).

Other evidence for the link between visual imagery and autobiographical memory comes from work involving individual variability, with studies reporting that participants with more vivid visual imagery during remembering produce memories that are more phenomenologically rich [53]. Other work has focused on how two forms of visual imagery, spatial and object [54], are related to autobiographical memory [55]. We demonstrated that the detrimental effects of visual interference with imagery during recall of detailed videos was related to spatial imagery ability [56]; performance of those with low spatial imagery abilities was spared. This finding suggests that spatial imagery ability is linked to forming broader relations and scaffolding within an imagined mental representation, whereas object imagery ability is linked to recalling specific perceptual details to 'color-in' an image of a past event ([55], see [57] for a related finding concerning future events and spatial contexts).

Whereas some individuals may have a strong preference to use an imagery-guided route to access autobiographical memories, others may use very little visual imagery to access their past [58]. This notion is reminiscent of the classic dual-coding theory of imagery [59] that states that memory can activate a verbal and an imagery-based representation in a nonexclusive manner. Indeed, it has been shown that differences in mnemonic strategies (e.g., verbal, visual) influence how well information is remembered in the laboratory, with concordant individual differences in patterns of brain activity, both at encoding and retrieval [60–63].

Along these lines, we have proposed that autobiographical memory, like other cognitive domains, can be considered a 'trait' that reflects stable individual differences in the manner in which people tend to access their past ([24,25]). Self-reported individual differences in autobiographical memory were shown to be related to intrinsic patterns of functional connectivity: Whereas medial temporal

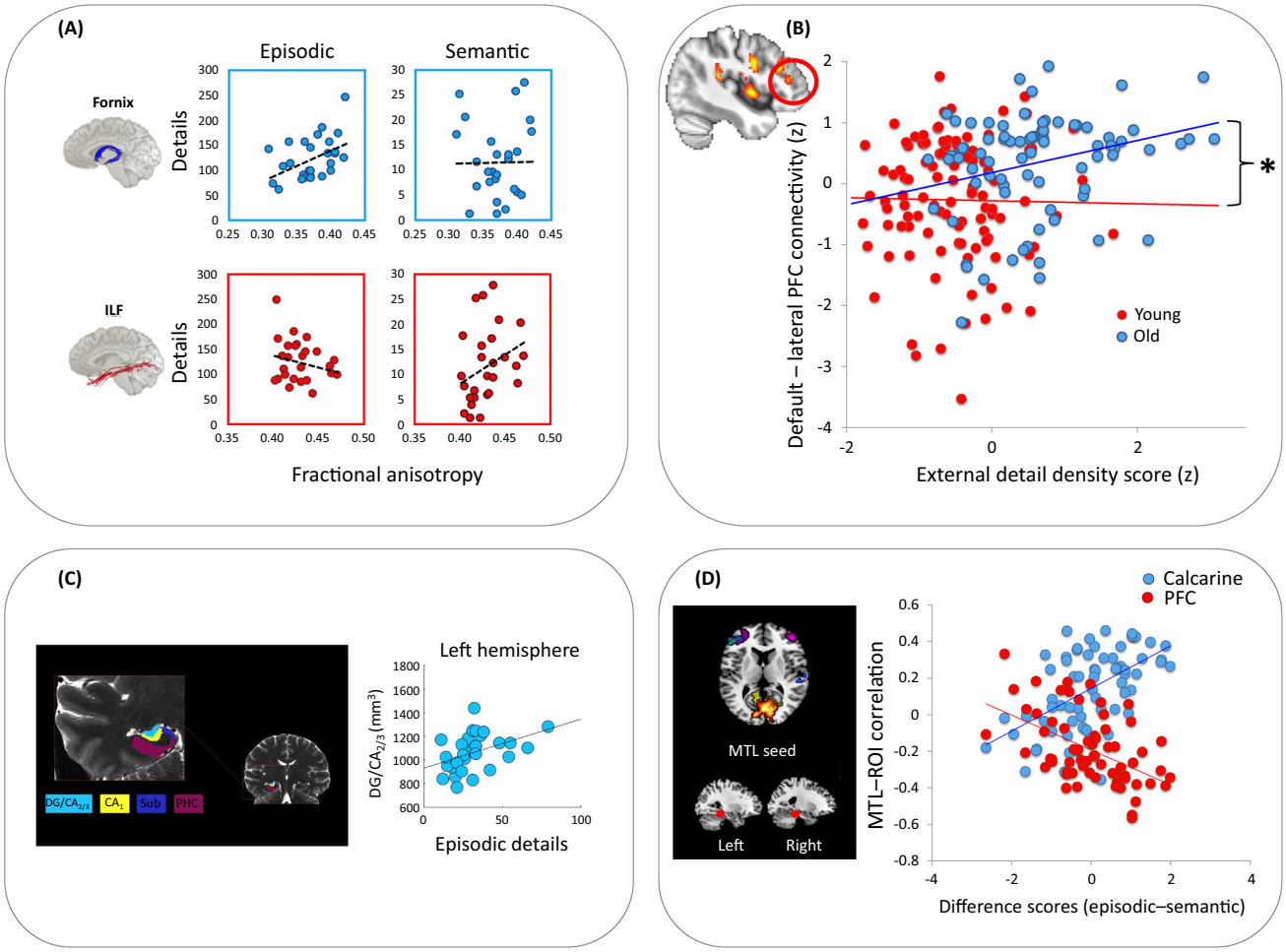

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Figure 1. Neural Correlates of Individual Differences in Autobiographical Memory. (A) Variability in episodic autobiographical memory, measured with the Autobiographical Interview (AI) [123], is associated with fornix white matter integrity, whereas variability in semantic autobiographical memory is associated with inferior longitudinal fasciculus (ILF) white matter integrity (figure adapted from [28] with permission from Elsevier). (B) In older adults, the tendency to shift towards a higher proportion of external AI details is associated with increased resting-state fMRI coupling between default and executive brain networks [e.g., lateral prefrontal cortex (PFC)] (figure adapted from [29] with permission from Elsevier). (C) Individual differences in episodic autobiographical memory on the AI are associated with variability in hippocampal subregions, namely the dentate gyrus/cornu ammonis region 2/3 (DG/CA2/3) and subiculum (not shown; figure adapted from [135] with permission from Wiley). (D) Individual differences in episodic versus semantic autobiographical memory [measured with the Survey of Autobiographical Memory (SAM)] [25] are associated with medial temporal lobe (MTL) connectivity, using functional (shown) and structural seeds. Warm colors depict the connectivity pattern that was positively associated with episodic–semantic scores (anatomical seed in yellow; functional seed in orange); Cool colors depict the pattern that was positively associated with semantic–episodic scores (anatomical seed in purple; functional seed in blue/green). The scatter plot depicts regions of interest (ROI) demonstrating these patterns, including the calcarine and lateral prefrontal cortex (PFC) (figure adapted from [24] with permission from Elsevier). CA1, Cornu ammonis region 1; PHC, parahippocampal cortex; Sub, subiculum.

lobe–occipitoparietal connectivity was related to an episodic and visual style of remembering, medial temporal lobe–lateral prefrontal connectivity was related to a more factual-based (semantic) style of remembering [24] (Figure 1). We speculate that one mechanism of individual differences in autobiographical memory, in extreme and also less extreme versions, is the likelihood of coactivating both or only activating one of these underlying mental representations.

While research on visual imagery has focused on the relative advantages of recalling vivid and rich images from autobiographical memories, there could be disadvantages to this form of

remembering. Retaining a vivid image of an autobiographical memory could limit the ability to integrate that memory with other experiences. That is, focusing on specific perceptual details of one experience may inhibit the ability to understand how this experience is similar to another one on a conceptual level, a process that is necessary for learning and generalization or making inferences [45]. Along these lines, it would also be of interest to assess people with HSAM on generative tasks that require mnemonic flexibility, such as imagining novel or future events. One might also predict that some individuals lacking rich visual re-experiencing may excel at tasks mediated by lateral prefrontal cortex, including abstraction and implicational and semantic reasoning ([56,64]; see Outstanding Questions). This notion is consistent with the association between endorsement of an advantage for semantic memory abilities and increased temporofrontal connectivity [12,24].

Is there a role of visual imagery in HSAM and SDAM? As noted above, researchers have recently described individuals with no visual imagery or aphantasia ([18–20], also see [14]), many of whom report an associated impairment in autobiographical recollection (see Outstanding Questions). Also noted above, laboratory-assessed memory impairments in individuals with SDAM are specific to the visual modality. Furthermore, SDAM participants showed reduced activation in response to autobiographical cues in regions thought to support visuospatial components of autobiographical memory, such as the precuneus [3], which is also implicated in individual differences in autobiographical memory more broadly [65] (Box 3). These findings raise questions about whether aphantasia and SDAM represent overlapping syndromes [14]. If so, these syndromes can provide a novel platform for investigating associations between imagery and memory. More direct evidence is needed to shed light on the role of visual imagery in SDAM (and the role of autobiographical memory in aphantasia), as well as to determine whether other forms of imagery (e.g., auditory, motor, tactile, etc.) are relevant.

Turning to HSAM, such individuals show no advantage for imagery of simple symbols and shapes [4]. However, these lower level tasks may not accurately capture the imagery processes characteristic of autobiographical memory, wherein many distinct elements of a remembered event must be dynamically combined as a scene [66,67].

Self-referential Processes

Autobiographical memories are by definition self-referential. The special status of the self in memory is demonstrated by the classic 'self-reference effect', wherein self-related information is remembered better than non-self-referential information [68,69]. Among the limited individual differences work in this research area, early work has suggested that variability in self-awareness or self-consciousness is associated with variability in the self-reference effect [70–72], that is, individuals prone to self-reflectiveness show a stronger self-reference effect in memory. Neuroimaging evidence suggests that the relationship between self-consciousness and the self-reference effect is moderated by variability in intrinsic functional connectivity between nodes of the frontoparietal control network and the hippocampus [73]. Moreover, individual differences in self-reflection are related to brain activation in ventromedial prefrontal cortex (a region implicated both in autobiographical memory and self-referential processes) during performance on an autobiographical memory task that focused on meaning extraction [74], suggesting that individuals with more extensive self-knowledge extract greater meaning from personal memories. The magnitude of the self-reference memory effect is associated with the propensity to engage in future thinking during a mind-wandering task [75], suggesting that the self-memory effect has adaptive value.

An intriguing, albeit speculative, hypothesis is that the mnemonic syndromes of HSAM and SDAM reflect alterations of the self-memory system (also see [76]). In HSAM, there is some

evidence that the personal nature of to-be-remembered information is relevant to their memory syndrome: individuals with HSAM are more adept at remembering their own experiences versus experiences provided by an experimenter (as measured using a 'staged event' approach) (Box 1) [4], and as noted earlier, their superior memory appears somewhat specific to autobiographical experiences relative to laboratory ones. Notably, Jill Price showed a strong tendency towards obsessiveness, particularly with respect to her personal past (see also [8]). Indeed, it has been suggested that the tendency of people with HSAM to riffle endlessly through dates and experiences is a compulsion [8]. Other work shows higher fantasy proneness in HSAM and the degree of fantasy proneness predicts the magnitude of their superior memory ([6,7]; also see Outstanding Questions). One hypothesis is that normal memory mechanisms that support the self-reference effect are enhanced in HSAM (also see [6] for a related discussion). Perhaps this propensity towards autobiographical or self-referential information is a dispositional trait that has cascade mnemonic effects in HSAM. In light of these ideas, it is intriguing that related factors such as curiosity play a role in laboratory-based memory (albeit measured at the state level, [77]). Of potential relevance of a self-referential mechanism in HSAM, anatomical analyses in such individuals (discussed above) show structural differences, relative to a comparison group, in brain areas implicated in autobiographical processes more generally, and self-referential processes in particular [32–34,78,79]. These include the uncinate fasciculus, a white matter tract that mediates information flow between the rostral portion of the temporal lobes (including medial temporal regions) and the ventral, medial, and orbital prefrontal cortices [80]; imaging work suggests that such prefrontal regions are particularly important for supporting the self-referential components of autobiographical memory [79]. Moreover, in a single case of retrograde autobiographical amnesia sustained due to a traumatic brain injury, uncinate damage was considered critical to 'autonoetic awareness', awareness of one's self as a continuous entity through subjective time [81,82; also see 83] That is, autonoetic awareness gives rise to the feeling that an event has happened to the self, enabling the sense of a first person ('mine') sense in recollection [84]. Accordingly, HSAM may reflect stronger communication between mnemonic and self-referential nodes of the autobiographical memory network via the uncinate fasciculus.

As for SDAM, these individuals may lack a first person, autonoetic connection to their past [3], though it is acknowledged that their mnemonic impairment extends to tasks that are not self-referential. Individuals with SDAM show reduced activation in nodes of the autobiographical memory network that have been linked to self-referential processing, including the medial prefrontal cortex [79; also see 85,86]. Indeed, damage to this area attenuates the self-reference effect [87]. Detailed structural analyses in SDAM have not yet been conducted, but it would be of interest to examine whether SDAM is associated with reduced structural integrity of the uncinate fasciculus or other temporo-frontal tracts to shed light on whether the neural alterations associated with HSAM are also at play in SDAM.

Affective Processes

Differences in the recruitment of affective processes may also underlie individual differences in autobiographical memory. This proposal stems from the well-documented enhancing effects of emotion for laboratory [88] and autobiographical memory [89–91]. There is a small yet growing body of evidence suggesting that trait differences (e.g., personality, psychiatric factors, genetics, etc.) play a role in emotional memory processes [92–96]. For example, both laboratory [94] and autobiographical memory studies [97] demonstrate a relationship between individual differences in trait anxiety and emotional memory phenomena such that individuals who are higher in trait anxiety tend to show stronger memories for emotional information. The personality traits of neuroticism and extroversion are associated with negative and positive autobiographical

memories, respectively (reviewed in [89]). These findings suggest there may be some interactive effect between trait level factors and emotional modulatory effects on memory. Perhaps such trait effects bias how information is encoded, for example by influencing emotional arousal [6,98,99].

The mnemonic alterations observed in HSAM (or SDAM) may involve a bolstering or attenuation, respectively, of the affective (emotional) enhancement that has been widely observed in memory [88,89,91] (see [17]). That is, individuals with HSAM may initially experience or relive events with greater emotional intensity, while those with SDAM may lack an emotional connection to their autobiographical experiences. From a physiological perspective, a similar hypothesis is that the modulatory neural-hormonal systems involved in emotional memory may be more sensitive in HSAM (i.e., they become activated even by modestly arousing experiences; see [17]), and perhaps the opposite holds true for SDAM. If this hypothesis is correct, these syndromes provide an interesting new platform for better understanding basic mechanisms associated with these modulatory effects on memory. The insights gained may in turn inform our understanding of how individual difference factors play a role in affect-based psychiatric disorders in which autobiographical memory alterations are a hallmark feature ([100]).

A comprehensive test of the hypothesis that affect-related processes are relevant to HSAM or SDAM requires experimental manipulations involving emotional versus non-emotional information. Although, HSAM individuals were not found to show superior memory relative to controls for emotional information presented in a laboratory task [4], an emotional modulatory effect in autobiographical memory may require longer delays or stimuli with greater self-reference. Yet, it is notable that another study showed that retrospectively reported emotional arousal in the week following 9/11 was not significantly associated with performance on the 10 Dates Quiz in 20 individuals with HSAM [6], although a nominal trend was observed. Such ratings of arousal may be contaminated by other factors inherent to this public event, such as subsequent news reports.

Although there is little support to date for an affect-related mechanism driving extreme cases of autobiographical memory, as noted above, a single case study report of HSAM (H.K.) showed increased volume of the right amygdala (~20%) [11], a finding that is relevant, given that this is a key region for processing emotional [101] and reward-related information [102]. The authors also observed greater amygdala–hippocampal coupling during resting state fMRI in this individual (although this individual's blindness clouds the interpretation of this finding). However, structural effects in the amygdala were not observed in a larger sample of HSAM participants [8]. As noted earlier, structural differences in portions of the basal ganglia (e.g., caudate, anterior putamen) were observed in this HSAM group relative to a comparison group, possibly related to concomitant elevated obsessive-compulsive tendencies in such individuals [8]. The basal ganglia is not considered a core node in the autobiographical memory network, yet greater activation (as measured with fMRI) in the caudate has recently been observed for positive, relative to neutral autobiographical memories [103], in keeping with its well-documented role in processing reward-related information more broadly (e.g., [104]). While much more research is needed, particularly at the behavioral level, these imaging studies hint at the possibility that the circuitry related to emotion and/or reward-related processing might be altered in HSAM and may be relevant targets for exploration in future studies of SDAM as well.

The Interactive Effects of Component Processes of Memory

In the foregoing section, we focused on the potential contribution of what likely represents only a subset of factors that are relevant to individual differences in autobiographical memory and to

the syndromes of HSAM and SDAM. Moreover, their contributions are unlikely to be mutually exclusive. For example, self-reference likely modulates the emotional significance of an experience (or vice versa; e.g., [105]). These factors may also modulate the vividness with which autobiographical events are experienced or retrieved. For instance, visual imagery is known to be associated with emotional factors in autobiographical memory, which in turn, can lead to autobiographical memory alterations. This has been shown in certain psychological disorders, such as PTSD: individuals with PTSD report stronger visual imagery and emotional responsiveness to autobiographical memories that are traumatic in nature, which in turn predicts the degree of recollection of such experiences [48]. Similarly, in nonclinical samples, individual differences in emotional processing style [53,96,106,107], social anxiety [108], self-esteem [43], or other personality characteristics [89] are associated with various aspects of autobiographical memory retrieval, as alluded to above (also see Outstanding Questions). While it is unclear how these factors work together, and whether they exert their effects, if any, at encoding versus retrieval (Box 2), more work on HSAM or SDAM, as well as across the spectrum, may help to determine the nature of the relationships among phenomenological component processes within autobiographical memory.

Concluding Remarks

Individual differences in cognitive abilities have been studied for spatial [22,109], perceptual [21], imagery [19,20,110] working memory [111], arithmetic [112], executive [113,114], and emotional [115,116] tasks, with implications for academic abilities, occupation, daily life function, and brain function. A similar body of research exists for mnemonic function, but until recently this has been based on laboratory tasks [60–63], which dissociate from autobiographical memory tasks at the behavioral and neural levels [3–5]. The topic of individual differences in autobiographical memory has been brought to the forefront by the dramatic descriptions of HSAM and SDAM, which may represent the extremes along a distribution of individual differences in autobiographical memory. It is remarkable that the identification of these syndromes occurred as a result of individuals seeking information from prominent memory researchers (Jim McGaugh and Endel Tulving); HSAM and SDAM were not heretofore known to exist (at least as developmental syndromes), nor were scientists looking for them [although Tulving had hypothesized the existence of SDAM in an online interview (http://www.science.ca), which prompted Susie McKinnon, the index SDAM individual, and later Nick Watkins [14], to come forward].

Although individual differences in autobiographical memory likely reflect reliable traits, there has been very little research on this topic. Researchers have examined the neural correlates of these differences through cognitive, neuropsychological, and neuroimaging methods. Yet this research has only just begun to address questions about mechanisms. The ideas proposed here speculatively suggest directions for exploring these. Investigations of individual differences in autobiographical memory should be targeted at the level of component processes [48] to reveal which processes are relevant to other cognitive abilities or daily life functions. At the anatomical level, whereas preliminary work suggests that there are neural correlates of individual differences in autobiographical memory, more fine-grained analyses are needed (e.g., examination of hippocampal subfields) (Box 3), particularly in the case of HSAM and SDAM. Moreover, preliminary work in one SDAM individual concerning neural oscillatory processes should be followed up in samples of individuals with HSAM and SDAM and across the spectrum of individual differences to provide insight into the circuitry of these syndromes. These methods will be most informative when coupled with robust behavioral assays that are appropriate for studying individual differences in autobiographical memory (Box 1). For instance, staged events [4,117–119], those that involve participants recollecting an autobiographical experience that was initially encoded in a naturalistic, albeit controlled and manipulated laboratory setting, provide a tool for measuring and reducing

Outstanding Questions

Are SDAM and aphantasia related? Some individuals with aphantasia (a lifelong deficit in visual imagery) report difficulties with autobiographical memory, suggesting these syndromes may be linked.

Could SDAM and aphantasia, which are defined by a deficit or lack of function in memory and imagery, confer a paradoxical advantage through corresponding facilitation of other functions, such as non-imagistic abstract or implicational reasoning?

Does HSAM involve episodic or semantic memory? Memory alterations in SDAM seem to be episodic, not semantic. Yet, this dissociation is less clear in HSAM, as such individuals not only have strong access to episodes, but can also recall a wealth of personal or public facts. Does their superior episodic memory drive access to such factual information, or vice versa?

Is there a genetic basis to HSAM or SDAM? There is little work on genetic factors related to autobiographical memory, yet laboratory memory studies suggest a genetic contribution. Limited evidence obtained in HSAM indicates that it does not run in families.

Are individual differences in memory linked to personality? Those who are high on openness or fantasy traits recall memories more vividly and these traits are elevated in HSAM. Obsessive-compulsiveness is also elevated in HSAM. One hypothesis is that their tendency to riffle through experiences is a compulsion. Whereas hoarding typically reflects compulsive retention of objects, HSAM may reflect the retention of experiences.

Are there implications of HSAM or SDAM for aging? One might predict that good memory poses an aging benefit, but an alternative idea is that such individuals have 'farther to fall'. By contrast, those with worse memory may be less susceptible to aging effects, which typically affects episodic but not semantic memory, as they may have developed alternative mnemonic strategies.

external (event-specific) noise so that internal (individual differences) factors can be examined (and verified) more readily. Research on memory mechanisms usually does not consider individual differences in mnemonic abilities or traits. Incorporation of this information in models of memory function may result in refinement of predictions, as such differences may correspond to alternative routes or pathways towards the same response or mnemonic outcome. Similarly, in clinical populations such as dementia or psychiatric conditions, consideration of baseline differences in mnemonic abilities or traits could inform diagnostic or prognostic measurement (see Outstanding Questions).

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