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The Association Between Past and Future Oriented Thinking: Evidence From Autism
Spectrum Disorder

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Abstract

A number of recently developed theories (e.g., the constructive episodic simulation, self-projection, and scene construction hypotheses) propose that the ability to simulate possible future events (sometimes referred to as episodic future thinking, prospection, or foresight) depends on the same neurocognitive system that is implicated in the recall of past events (episodic memory). In this paper, we argue that autism spectrum disorder (ASD) offers an ideal test of such theories, given that it is a developmental disorder that is characterized by impairments in episodic memory. Each of these theories would predict concomitant impairments in episodic future thinking among individuals with ASD. We review evidence concerning episodic future thinking in ASD, as well as studies of prospective memory (remembering to do something in the future), planning, navigation, and theory of mind, which some theories suggest also rely on the same mechanism as episodic future thinking.

Keywords

Autism spectrum disorder; episodic memory; episodic future thinking; mental time travel; planning; prospective memory

Introduction

Past and future oriented cognition can take multiple forms. Prominent examples include the capacity to recall past experiences (episodic memory) or simulate future experiences (episodic future thinking/foresight/prospection), prospective memory (remembering to do something in the future), and planning. It makes intuitive sense that our ability to cognize about the future should depend on our semantic knowledge base and our memory for past events. Indeed, a number of researchers have highlighted the apparent neural overlap between past and future-oriented cognition (e.g., Buckner & Carroll, 2007; Hassabis, Kumaran, & Maguire, 2007; Okuda, Fujii, Ohtake, Tsukiura, Suzuki, et al., 2003). For example, based on a meta-analysis of previous neuroimaging studies, Spreng, Mar, and Kim (2009) proposed a set of functional neural correlates that is common both to episodic memory and to episodic future thinking, within specific medial and lateral prefrontal, medial and lateral temporal, parietal, and occipital regions.

A number of recent theoretical proposals have explicitly linked aspects of past and future oriented thinking at the cognitive level (e.g., Suddendorf & Corballis; Wheeler, Stuss, & Tulving, 1997). One of the most influential of these theories, the “constructive episodic simulation hypothesis” (Schacter & Addis, 2007), postulates that simulation of future events relies on the episodic memory system to flexibly draw on and recombine elements of past experiences to generate novel event scenarios. Thus, both episodic memory and episodic future thinking are said to involve *constructive* processes, although episodic future thinking requires greater flexibility, given that there are no constraints on the possible combinations of features included in the event representation (whereas true episodic memory is constrained by the specific combination of features present at encoding).

The constructive episodic simulation hypothesis is not the only theory to suggest that the ability to remember past experiences and the ability to imagine future experiences rely on some common cognitive process. Hassabis and Maguire (2007) have suggested that each of these abilities rely on the capacity for “scene construction”, which refers to the generation and maintenance of a coherent, multimodal spatial representation. They also suggest that scene construction may be involved in certain forms of navigation (Hassabis & Maguire, 2009). Buckner and Carroll (2007) have gone a step further in suggesting a common cognitive process involved in numerous processes/abilities including episodic memory, episodic future thinking, navigation, and theory of mind. They argue that this common process is the capacity for “self-projection”, which they define as the ability to shift from one’s current perspective to alternative perspectives (temporal, spatial, or mental). One arguable difficulty with the self-projection theory is that it is somewhat all-encompassing. If self-projection is merely moving from one perspective to another, then there seems little to distinguish this ability from what some would consider “thinking” (e.g., Hobson, 1991). A less encompassing version (or related theory) of the self-projection hypothesis emphasises the temporal aspect of perspective shifting, suggesting that mentally projecting oneself backward or forward in time (“mental time travel”) allows episodic memory and episodic future thinking, respectively (Sudendorf & Corballis, 2007; Wheeler, Stuss, & Tulving, 1997). Hassabis et al. (2007, p.14372) argue that “self-projection” can be “broken down into at least two components with dissociable neural bases: a network centred on the hippocampus responsible for scene construction, with the amPFC [anterior medial prefrontal cortex], PCC [posterior cingulate cortex] and precuneus mediating self-projection in time, sense of familiarity, and self-schema” (Hassabis et al., 2007, p.14372). They argue that whereas all of the abilities identified by Buckner and Carroll require scene construction (e.g., navigation), only some additionally require self-projection (in time) (e.g., episodic memory).

At present, the scene construction and self-projection hypotheses rely almost exclusively on support from neuroimaging data and there is only limited direct evidence that these abilities are associated on the behavioural level. Only the link between episodic memory and episodic future thinking has been robustly observed in cognitive-experimental studies.

There is now considerable empirical evidence for the proposed overlap between episodic memory and episodic future thinking. Research on young typically developing children suggests that the ability to describe past experiences develops in parallel with the ability to describe future experiences (Suddendorf, 2010). Similarly, research on older adults suggests that the specificity of past and future thinking declines in tandem with age (Addis, Wong, & Schacter, 2007). If the capacity for episodic future thinking depends on the episodic memory system, as is widely supposed, any disorder that is characterized by diminished episodic memory should also be characterized by a corresponding deficit in episodic future thinking. Certainly, it has been shown that individuals with acquired amnesia, who are unable to remember past personal experiences, show an equivalent deficit in imagining future personal experiences (Klein, Loftus, & Kihlstrom, 2002; Tulving, 1985). The same is true of individuals with depression and individuals with schizophrenia, who show attenuated memory for past personal experiences (D'Argembeau, Raffard, & Van der Linden, 2008; Williams, Ellis, Tyers, Healy, Rose et al., 1996). However, none of these disorders is early-emerging or inherently developmental in nature. Thus, they cannot speak to the question of whether episodic memory and episodic memory are potentially dissociable in development. Indeed, the picture is somewhat more complex in the case of *developmental* amnesia.

Consistent with findings from cases of acquired amnesia, Kwan, Carson, Addis, and Rosenbaum (2010) found that H.C., a 20-year-old woman with developmental amnesia (resulting from diminished bilateral hippocampal development), showed a level of diminution in episodic future thinking that was concomitant with her level of diminution in episodic memory. However, Hurley, Maguire, and Vargha-Khadem (2011) retested H.C. using an alternative method and found that she did, in fact, appear to engage in episodic future thinking at a level comparable with typical individuals matched on age and IQ. Hurley et al. suggested that Kwan et al.'s method may have underestimated H.C.'s abilities. Using the same method as Hurley et al., Maguire, Vargha-Khadem, and Hassabis (2010) found that Jon, another individual with developmental amnesia (also resulting from bilateral hippocampal atrophy), also showed intact episodic future thinking despite his severely impaired episodic memory.

These findings provide preliminary evidence that these abilities may, in fact, be dissociable, and call into question any theory that links episodic memory with episodic future thinking. They seem to suggest that the capacity for episodic future thinking may be able to develop even if the capacity for episodic memory does not. Of course, evidence based on individual cases is rarely highly compelling. On the other hand, if dissociations are observed within whole groups of individuals from particular populations, the case against such theories would be considerably stronger. One particular disorder, autism spectrum disorder (ASD), offers a unique opportunity to test the constructive episodic simulation, scene construction, and self-projection hypotheses (and other, related theories).

ASD is a lifelong developmental disorder, diagnosed on the basis of impairments in social interaction, communication, and behavioural flexibility (American Psychiatric Association, 2000). It is also characterized by a particular profile of cognitive strengths and weaknesses, including a specific deficit in episodic memory. As such, ASD provides an ideal

test of the hypothesis that episodic memory and episodic future thinking are interdependent. The constructive episodic simulation, self-projection, and scene construction hypotheses (among others) should each predict concurrent impairments in episodic future thinking in ASD. Below, we provide a brief summary of the evidence that ASD is associated with deficits in episodic memory. We then go on to consider whether there is any evidence for corresponding deficits in episodic future thinking. Finally, we consider research on ASD that may help to distinguish between some of the competing theories that attempt to account for the apparent relationship between episodic memory and episodic future thinking.

Episodic Memory in ASD

Episodic memory can be assessed using a variety of techniques, many of which have been utilized in ASD research (see Lind, 2010, for a review). Arguably the most definitive tests require participants to retrieve multiple episodic details and contextual features, as opposed to single items (as commonly required in simple tests of recall or recognition, for example). Tests of personal episodic or “autobiographical” memory are perhaps the most pertinent example, particularly in the present context. Although methodological details vary between studies, they all require participants to retrieve personally relevant past experiences, which involve complex, multi-modal event representations.

Autobiographical memory has been explored in ASD using a variety of paradigms, including interviews, cueing tasks, fluency tasks, narrative tasks, and questionnaires (Adler, Nadler, Eviatar, & Shamay-Tsoory, 2010; Bruck, London, Landa, & Goodman; 2007; Crane & Goddard, 2008; Crane, Goddard, & Pring, 2009; Crane, Goddard, & Pring, 2010; Goddard, Howlin, Dritschel, & Patel, 2007; Klein, Chan, & Loftus, 1999; Lind & Bowler, 2010; Losh & Capps, 2003; Tanweer, Rathbone, & Souchay, 2010). These studies clearly

indicate significant impairments in personal episodic memory. The main findings are that participants with ASD tend to generate fewer autobiographical memories *per se* and those that they do generate tend to be characterized by reduced episodic specificity. These impairments are typically associated with medium to strong effect sizes. For example, in one of the most recent studies, Tanweer et al. (2010) asked intellectually high-functioning adults with ASD and typical comparison adults, matched on age and IQ, to generate autobiographical memories from three discrete lifetime periods (between 0 and 17 years of age; during the last 5 years but excluding the last 12 months; and during the last 12 months). Participants were asked to “recall a personal event, which occurred only once, at a particular place and date, and lasted several minutes or hours but lasted less than a day”. Participants were given two minutes to recall as much detail as possible. The results indicated that participants with ASD recalled fewer autobiographical memories and fewer “strictly episodic” (i.e., scored maximum points for episodic detail) autobiographical memories.

One common criticism of studies of autobiographical memory in ASD is that the experimental tasks rely heavily on narrative skills, which are often considered to be impaired in this disorder (e.g., Capps, Losh, & Thurber, 2000). Thus, group differences on many autobiographical memory tasks could potentially be attributed to limitations in language ability, rather than limitations in memory. Surprisingly few studies have considered the possible mediating role of narrative ability. However, Losh and Capps (2003) found that even when participants with ASD and comparison participants were matched for narrative ability (assessed with a picture book narration task), participants with ASD still had significant difficulty recounting past personal experiences. This is not to say that limitations in narrative skills among individuals with ASD have no effect on their performance in other studies of autobiographical memory. However, it does suggest that they have memory limitations that affect them over and above these linguistic deficits.

Episodic memory difficulties are also revealed in studies that adopt the “remember-know” paradigm (Tulving, 1985). This classic paradigm exploits the fact that we are able to make reliable introspective judgments regarding the phenomenal qualities associated with memory retrieval. Episodic retrieval or “remembering” is uniquely associated with a feeling of re-living the previously experienced event – one is able to recall specific contextual details from the point of encoding. On the other hand, semantic retrieval or “knowing” is associated with a feeling of familiarity but no sense of re-living a past event – one is unable to recall any contextual details from the point of encoding. Remember-know procedures are most frequently used to ascertain the relative contributions of episodic and semantic memory to recognition memory task performance. Typically, for all items identified as “old” (i.e., previously studied) at test, the participant will be asked to state whether they actually “remember” the item from the study list or whether they simply “know” it was there. Using this type of procedure, Bowler and colleagues (2000, 2007) have shown that, despite showing levels of recognition memory equivalent to typical comparison adults matched on age and IQ, adults with ASD showed diminished rates of remembering and elevated rates of knowing. This suggests that individuals with ASD have impaired episodic memory, but are able to compensate using their intact semantic memory.

Each of these lines of research indicates that individuals with ASD have significant difficulty with episodic memory. Thus, as stated above, ASD offers the ideal test of the hypothesis that episodic future thinking is dependent on (or dissociated from) episodic memory.

Episodic Future Thinking and its Relation to Episodic Memory in ASD

Only recently have researchers attempted to explore episodic future thinking in ASD. In the first study of its kind, Lind and Bowler (2010) set out to test the hypothesis that if episodic memory is impaired in ASD (as the weight of the evidence suggests it is), episodic future thinking should be equally diminished. They adapted a method originally devised by D'Argembeau and Van der Linden (2004). Adults with ASD and typical comparison adults, closely matched on age and IQ, were asked to recall 7 events from particular time periods in the past (ranging from today to 10 years ago) and to imagine 7 events from corresponding time points in the future (ranging from today to in 10 years time), and give verbal descriptions of them. Importantly, participants were asked to generate *specific* events lasting from a few minutes to a few hours and certainly no longer than a day. Verbal responses were subsequently coded for episodic specificity. It was found that participants with ASD generated significantly less specific past and future events than comparison participants (medium effect size), suggesting that both episodic memory and episodic future thinking are diminished in this population.

One particularly intriguing finding that emerged from this study was the fact that although past and future oriented thinking were significantly correlated within the comparison groups ($r = .72$) (consistent with most previous research), they were not significantly correlated within the ASD group ($r = -.25$). Lind and Bowler (2010) speculated that the lack of a significant positive relationship within the ASD group may have reflected the fact that individuals with ASD are less likely to draw on elements from *episodic* memory in order to simulate possible future experiences, as typical individuals do. Rather, in trying to imagine future events, individuals with ASD may draw more heavily on elements from *semantic* memory.

Crane, Lind, and Bowler (under review) recently attempted to replicate Lind and Bowler's (2010) findings using an alternative method, which involved a sentence completion

task designed to elicit past and future event descriptions (following Raes, Hermans, Williams, & Eelens, 2007; also Anderson & Dewhurst, 2009). Matched participants with and without ASD were presented with a series of stems such as “*I still remember well how...*” and “*Next year I...*” and asked to complete the sentences. In contrast to Lind and Bowler’s findings (and indeed the majority of research on episodic memory in ASD), Crane et al. did not find any statistically significant group differences in task performance and all associated effect sizes were negligible or small. While these results should not be dismissed altogether, it is quite possible that the failure to observe group differences was an artifact of the particular measure used. Arguably, the sentence completion task was a somewhat insensitive measure of episodic memory and episodic future thinking. Notably, the task instructions did not ask participants to generate *specific* events, and the sentence stems (e.g., “*In the future...*”) were not particularly conducive to eliciting specific (i.e., episodic) event descriptions. Thus, any potential underlying group differences may have been masked by elevated levels of more general responses among comparison participants. Moreover, Crane et al.’s task did not include any time constraints, which may have afforded greater opportunity for compensatory strategies among the ASD group. Nevertheless, the inconsistency in results across these two studies strongly suggests the need for further research in order to fully elucidate these issues.

Although there is currently only limited direct evidence for impairments in episodic future thinking in ASD, other indirect sources of evidence may shed further light on the debate. If there genuinely are ASD-specific impairments, as recent theories suggest there should be, we should expect to see deficits in other abilities that require (or are supported by) episodic future thinking. Prospective memory and planning are prime examples of such abilities and there has been a substantial amount of research into these abilities in ASD.

Prospective memory in ASD

Prospective memory is the ability to carry out a planned action (e.g., to pay a bill on time, to keep an appointment, or to turn off the bath taps before the bath overflows) at the appropriate point, without explicit instruction to do so (see Kliegel, McDaniel, & Einstein, 2008).

Whereas “event-based” prospective memory involves remembering to carry out an intention upon the occurrence of a specified event (e.g., to remove a pan from the stove when the timer goes off), “time-based” prospective memory involves remembering to execute an intention at a particular time (e.g., to remove the pan from the stove in 10 minutes). Over a dozen neuroimaging studies have shown that performance on prospective memory tasks is consistently associated with activation in the rostral prefrontal cortex (for a review, see Burgess, Gonen-Yaacovi, & Volle, 2011). Although activation of the rostral prefrontal cortex is relatively insensitive to changes in superficial task structure/content (suggesting that it relates specifically to a super-ordinate prospective memory component), results suggest that BA10 activation in time-based tasks is more medial than in (laterally-activated) event-based tasks (Okuda, Fujii, Ohtake, Tsukiura, Yamadori et al., 2007). Particularly important is the recent finding of Volle, Gonen-Yaacovi, Costello, Gilbert, and Burgess (2011) that lesions to right BA10 are associated with specific deficits in time-based, but not event-based, prospective memory.

On a theoretical level, it makes intuitive sense that episodic future thinking should be involved in prospective memory. As Okuda et al. (2007, p.244) suggest, in prospective memory tasks one may need “a clear insight into one’s own future behaviour that can be considered a kind of future mentalizing component”. Specifically, during a prospective memory task, at the point of encoding one’s intention to act at later point, it may be important to mentally project oneself forwards in time to envisage the future scenario in which that intention will subsequently be executed. For example, say that one’s intention is to buy milk

from the supermarket on one's walk home from work. By imagining at the time of encoding the intention, one walking the route past the supermarket, one can create conditions mentally that are similar to those one will actually experience when one passes the supermarket.

Theoretically, this could stimulate spontaneous retrieval of one's intention when one actually passes the supermarket at the end of the day, precisely because the environmental conditions one finds oneself in at the point of retrieval are similar to those imagined at the point of encoding. This suggestion is given neurobiological plausibility by findings suggesting that similarity between brain activity at encoding and brain activity at retrieval predicts successful prospective memory performance (e.g., West & Ross-Munroe, 2002). As Gilbert, Armbuster, and Panagiotidi (2012, p.11) argue, given that "imagining a particular situation can engender similar brain activity to actually being in that situation (e.g., Stokes, Thompson, Cusack, & Duncan, 2009), thinking about a specific future cue when forming an intention will tend to increase the similarity between brain activity at encoding and retrieval".

Supporting the idea that prospective memory and episodic future thinking are linked, 12 out of 13 imaging studies of episodic future thinking have found BA10 to be implicated. Equally important is the specificity of the link between prospective memory and future thinking, rather than between prospective memory and thinking about the past. For example, Addis et al. (2007) used a classic measure of episodic memory and episodic future thinking, in which typical adults had to describe events that they had experienced in the past and events that they might experience in the future. Addis et al. found that activation of right medial BA10 was significantly greater when possible future events were described than when previously experienced events were described. Thus, at the neurobiological level, imagining oneself in the future, rather than remembering oneself in the past, appears to be particularly closely related to prospective memory (Okuda et al., 2007; Volle et al., 2011). If this hypothesis concerning how future thinking could be involved in prospective memory is

correct, and if future thinking ability is diminished in ASD, then we should expect to see prospective memory deficits among people with this disorder. However, results from the few studies of prospective memory in ASD have been mixed.

Recently, we completed a study of both time-based and event-based prospective memory among 21 children with ASD and 21 neurotypical comparison participants (Williams, Lind, Boucher, & Jarrold, under review). The ongoing task in each condition (time-based/event-based) was a 2D computer-based game that involved driving a car down a street with the aim of collecting gold tokens and avoiding obstacles. Participants completed each of the event-based and time-based conditions in counterbalanced order. In the event-based condition, the prospective memory component involved remembering to press a particular keyboard key every time a lorry was encountered in the game. In the time-based condition, the prospective memory component involved remembering to refuel the car in a period between 60 and 80 seconds after the beginning of the game, this critical period being indicated by a fuel gauge turning from green to red. Participants could check the fuel level by pressing a particular key, which displayed the gauge for three seconds, after which it disappeared. We found a significant interaction between diagnostic group and task condition. This interaction reflected (a) significantly diminished time-based prospective memory performance, and (b) non-significantly superior event-based prospective memory performance among participants with ASD. Before considering the results of other studies and the theoretical significance of the findings on prospective memory in ASD, we should highlight that our study has two advantages over other studies in the field. The first advantage is that the participant groups were very closely matched for age, and verbal and non-verbal intelligence (all effect sizes associated with differences between groups were negligible; Cohen's $d_s \leq 0.18$). This close matching ensures that any between-group differences can be specifically attributed to diagnostic status rather than to extraneous factors,

such as age and IQ differences. The second advantage is that ours is the only study to explore both event- and time-based prospective memory in the same sample of individuals with ASD. This allows us to gain a clear picture of the profile of prospective memory abilities in ASD, rather than having to compare across studies.

Four other studies have explored prospective memory in ASD. In keeping with our findings, Altgassen, Williams, Bölte, and Kliegel (2009) observed diminished time-based prospective memory among 11 children with ASD. Also in keeping with our findings, Altgassen, Schmitz-Hübsch, and Kliegel (2010) observed no significant differences in event-based prospective memory performance between 19 children with ASD and 19 comparison participants. The authors note that the effect size for the between-group difference in experimental task performance was small (Cohen's $d = 0.25$) and that, as such, there was no hint of any clinically meaningful prospective memory difficulty among this sample of individuals with ASD. In contrast, Brandimonte, Filippello, Coluccia, Altgassen, and Kliegel (2011) reported diminished performance on an event-based task among 10 children with ASD, relative to 10 comparison participants. However, in this study, participants with ASD were not closely matched for verbal intelligence. According to our calculations, based on data provided by M. Brandimonte (personal communication, January 31, 2012), children with ASD had notably lower verbal IQ scores than comparison participants, with an associated effect size (Cohen's d) of 0.67 (medium effect). Thus, the difference between the groups in event-based prospective memory could merely be the result of lower levels of intellectual ability among the participants with ASD, rather than any ASD-specific deficit in prospective memory.

Finally, a study of “everyday memory” that involved closely-matched participant groups was conducted by Jones, Happé, Pickles, Marsden, Tregay et al. (2011). Participants completed selected tasks from the Rivermead Behavioural Memory Test (Wilson, Cockburn,

& Baddeley, 1985). This naturalistic test assesses various domains of memory functioning across a number of different sub-tests, three of which assess event-based prospective memory. Adopting an approach that is common within the literature on the Rivermead, Jones et al. calculated a composite prospective memory score based on performance across these three subtests and reported a significant event-based prospective memory impairment in ASD (although the effect size was only small; $d = 0.40$). However, Jones et al. did not exclude participants who had failed to encode/store the prospective memory instructions in memory. As highlighted above, an individual who has not successfully stored the prospective memory instruction in retrospective memory cannot succeed on the prospective memory task. But, in this instance, we would not want to conclude that diminished performance was due to a failure of the cognitive mechanisms that underlie prospective memory uniquely. It is for this very reason that the vast majority of studies exploring prospective memory among typical individuals exclude participants who cannot recall the prospective memory instructions. If participants from each diagnostic group who failed the retrospective memory control questions were excluded, there was no hint of any significant between-group differences in event-based prospective memory performance (see Williams, Lind, Boucher, & Jarrold, under review).

From this brief review of the existing literature, it seems fair to say that, despite some methodological concerns about some studies, a reasonably consistent profile of prospective memory performance is observed in ASD. This profile is characterised by impaired time-based prospective memory, but unimpaired event-based prospective memory. The question is, if future thinking contributes to successful prospective memory, and if future thinking ability is diminished among people with ASD, then how is it possible for event-based prospective memory to be unimpaired in this disorder? Intuitively, it seems as important to project oneself mentally forward in time to pre-experience an actual *event* as it is to project

oneself mentally forward in time to pre-experience a particular *time period*. Therefore, intuitively, future thinking skills should be at least as involved in event-based prospective memory as in time-based prospective memory.

On the one hand, it may be that the finding of unimpaired event-based prospective memory in ASD should provide an indication that prospective memory and future thinking are not as linked as hypothesized. This point of view is expressed clearly by Hudson, Mayhew, and Prabhakar (2011, p.126):

Despite the fact that prospective memory tasks can be considered future-oriented, it is not evident that they involve the same kinds of hypothetical thinking and/or mental simulation that are involved in episodic foresight... and planning tasks. Successful performance on prospective memory tasks depends largely on attentional processes... The degree to which one has mentally simulated the target action in advance may not impact performance

On the other hand, it is possible that future thinking can contribute to successful prospective memory, as hypothesized, but that success can be achieved via alternative means – alternative means that people with ASD employ to succeed on event-based prospective memory tasks. The logic proposed above was that, at the point of encoding one's intention, imagining oneself in the future aids the spontaneous retrieval of the intention at the appropriate point (because the environmental conditions one finds oneself in at the point of retrieval are similar to those imagined at the point of encoding). This kind of “spontaneous recall” of intentions during prospective memory tasks is reported by the majority (around 70%) of typical adults and children (e.g., Ward, Shum, McKinlay, Baker-Tweney, & Wallace, 2005). However, successful prospective memory could be achieved merely by keeping one's intention “at the

forefront of one's mind" constantly (e.g., constantly reminding oneself that one needs to buy milk from the supermarket on the walk home from work). Under such conditions, successful prospective memory would depend almost entirely on one's working memory ability, rather than on future thinking. The disadvantage of this strategy is that, although prospective memory will be successful, working memory is not free to be employed for one's other ongoing activities, which might decrease behavioural flexibility. Working memory is often considered a relative strength among people with ASD (e.g., Ozonoff & Strayer, 2001) and verbal rehearsal is a common strategy among people with ASD to maintain information in short-term memory (Williams, Happé, & Jarrold, 2009; Williams, Bowler, & Jarrold, 2012). Thus, it is possible that people with ASD in the studies of event-based prospective memory conducted to date have simply relied on working memory to complete the prospective memory tasks successfully, despite diminished future thinking.

Of course, this idea relies on the supposition that event-based prospective memory tasks are more amenable to mediation via working memory/continuous monitoring than time-based tasks are; otherwise, why did participants with ASD fail to use such a continuous monitoring strategy to succeed on experimental tasks in studies of time-based prospective memory? However, there is reason to believe that this supposition is correct: event-based prospective memory tasks place a lower demand on executive control (particularly cognitive flexibility/set-shifting) than time-based tasks do, because in event-based tasks the event can automatically cue/trigger a shift in attention from the ongoing task to the prospective memory task. In contrast, time-based prospective memory requires self-initiated shifting over and above any working memory abilities.

Planning in ASD

Theoretically, the primary function of episodic future thinking is to support planning. According to this view, the ability to mentally simulate possible future scenarios enables individuals to test alternative plans of action without the potential risks associated with actually carrying out those (potentially flawed) plans of action (Currie, 1995; Suddendorf & Corballis, 2007). If true, any disorder that involves diminished episodic future thinking should also involve diminished planning skills. The most commonly used laboratory-based measures of planning abilities in the neuropsychological literature are the Tower of London and Tower of Hanoi tasks (Shallice, 1982). The traditional version of the Tower of London task consists of three to five coloured disks that can be arranged on three individual pegs. The aim of the task is to transform, in as few moves as possible, one arrangement of disks (the start state) into another arrangement (the goal state) by moving the disks between the pegs, one disk at a time. To reach the goal state in as few moves as possible requires efficient planning (e.g., Owen, Downes, Sahakian, Polkey, & Robbins 1990).

Although the Tower of London is considered a classic test of frontal lobe functioning, individuals with medial temporal lobe damage show significant impairment on variants of this task (e.g., Xu & Corkin, 2001). Of course, one explanation for this is that problems with episodic memory for one's prior moves results in the repetition of already performed changes. Hence, whereas an individual with intact episodic memory could recall mistakenly moving the red disk to the left peg (mistaken in the sense that the move ultimately led away from the goal state), an individual with amnesia may not recall the mistake and, thus, tend toward making the same mistake again. However, another possibility is that a difficulty with episodic *future thinking* is the immediate cause of planning difficulties among people identified as having episodic memory deficits. Clearly, as in the case of everyday planning, imagining the sequence of possible, alternative future steps (moves, in this case) will support efficient planning. Of course, in addition to any contribution of episodic future thinking to

planning performance, the Tower of London involves multiple components, including goal monitoring, strategy selection, and inhibitory control (e.g., Scholnick & Friedman, 1993). Thus, diminished planning ability could arise from deficits in any of these abilities, not just episodic future thinking. However, if ASD is *not* characterized by diminished planning, then the suggestion that episodic future thinking is genuinely attenuated in this disorder is weakened.

In fact, for many years a deficit in planning was considered pervasive in ASD (e.g., Pennington & Ozonoff, 1996). However, this idea has been questioned recently. In a thorough review of studies of planning (and other) abilities in ASD, Kenworthy, Yerys, Anthony, and Wallace (2008) noted a striking pattern of performance on the Tower of London task among individuals with this disorder. They noted that, whereas the vast majority of studies involving experimenter-administered Tower of London tasks observed diminished planning performance in ASD, the majority of studies employing computer-based administration found undiminished performance. Kenworthy et al.'s explanation for this was that planning problems in ASD are caused by a general difficulty with following socially mediated rules, rather than with difficulties in executive functioning, or episodic future thinking.

If it is true that individuals with ASD do not have difficulty with planning in contexts that are not directly socially mediated (i.e., in computer Tower of London tasks), then this is problematic for the idea that ASD involves diminished episodic future thinking. There does not appear to be any obvious reason to believe that episodic future thinking would contribute to experimenter-administered Tower of London tasks, but not to the very same tasks when they are presented on a computer.

Recently, we explored this issue explicitly by administering (in counterbalanced order) both computerized and experimenter-administered Tower of London tasks among a

common sample of children with ASD, and age- and IQ-matched comparison children (Williams, Lind, & Jarrold, in preparation). This was the first study, to our knowledge, to compare computerized and experimenter-administered tasks directly, and it therefore provides the most stringent test of Kenworthy et al.'s (2008) hypothesis. In fact, we found no hint of any interaction between group and task administration. Rather, participants with ASD performed significantly less well than comparison participants on both types of task.

The evidence presented, thus far, in this review is relevant to the hypothesis that episodic memory and episodic future thinking are interrelated. However, this particular hypothesis is common to a number of theories. In the following section, we briefly consider whether evidence from ASD can help us to distinguish between the constructive episodic simulation, self-projection, and scene construction theories. The scene construction theory would predict additional impairments in navigation amongst individuals with ASD, and the self-projection hypothesis would predict additional impairments in navigation and theory of mind.

Navigation in ASD

With respect to the domain of spatial navigation, to our knowledge, only one published study (Caron, Mottron, Rainville, & Chouinard, 2004) has investigated this ability in ASD. This study assessed navigation amongst 16 intellectually high-functioning adolescents and adults with ASD and 16 comparison adolescents and adults in a small-scale, human-sized labyrinth setting. No significant group differences in task performance were observed. This would seem to speak against the scene construction and self-projection theories. However, we conducted a power analysis, which indicated that the study did not include a sufficient number of participants ($N = 64$) to detect even a large effect if present on 80% of occasions.

Thus, further research is necessary in order to establish whether individuals with ASD experience navigation difficulties, particularly when confronted with larger-scale, realistic environments, rather than the small-scale labyrinth setting employed in Caron et al.'s study (we are currently in the final stages of conducting such a study; Lind, Bowler, Raber, and Williams, in preparation).

Theory of mind in ASD

According to the original definition of the term, theory of mind (ToM) is the ability to attribute mental states to self and others in order to explain and predict behavior (Premack & Woodruff, 1978). Key to ToM is an understanding that people (self and others) hold perspectives about reality. As such, ToM is thought to require “metarepresentation” (Leslie, 1987; Perner, 1991; Pylyshyn, 1978).

It is uncontroversial to state that ASD involves diminished ToM (e.g., Happé, 1995) and that the ToM account of ASD has been the most influential cognitive-level explanation of the disorder to date. The fact that ToM is diminished in ASD is consistent with the self-projection hypothesis of the relation between episodic memory and episodic future thinking (Buckner & Carroll, 2006). Buckner and Carroll use the term “simulation” to describe the mental representation of alternative states of reality. They argued that ToM, episodic future thinking, episodic memory, and navigation are all similar in requiring simulation “of an alternative perspective, or in the case of theory of mind, a simulation that considers an alternative perspective” (p.46). In support of their argument that ToM and future thinking are inter-linked, they highlight data from neuroimaging studies that suggests that the temporoparietal junction is involved in both abilities among typical adults.

Although a ToM impairment in ASD is consistent with the self-projection hypothesis, we are not convinced that the finding necessarily supports the theory. First of all, there is still debate about the role of the temporoparietal junction in ToM (e.g., Mitchell, 2008). Indeed, the temporoparietal junction may not be associated with ToM among typical *children*, even though it is among *adults* (Kobayashi, Glover, & Temple, 2007). More important, in our view, is a consideration of the requirements of ToM at the cognitive level. Buckner and Carroll's suggestion that ToM involves simulation of another perspective is reminiscent of (if not synonymous with) the simulation theory of ToM (e.g., Goldman, 2006). Broadly-speaking, simulation theory equates ToM with an *ability* (i.e., to simulate another's perspective), whereas the major alternative account (the "theory-theory") equates ToM with *knowledge* (i.e., a theory) of mental states. The simulation theory has come under considerable scrutiny and is considered by many to be inadequate as a complete explanation for ToM ability (e.g., Carruthers, 2009). For one thing, merely simulating/representing an alternative state of affairs (a perspective, in this case) does not necessitate knowledge about representation itself (it necessitates knowledge only of the *content* of the representation). Yet, for most theorists, ToM involves knowledge of (mental) representation itself (i.e., metarepresentation). As such, it is not clear that "a shift from the present perspective to a simulated model of an alternative world" (Buckner & Carroll, 2006, p.51) is sufficient for a ToM in the same way that it is (arguably) sufficient for episodic memory and episodic future thinking.

Differentiating the self-projection, scene construction, and constructive episodic simulation hypothesis using evidence from ASD

Each of these key theories is similar in arguing that episodic memory and episodic future thinking are fundamentally linked; episodic memory and episodic future thinking they rely on largely the same underlying cognitive mechanism/process, and share the same neurobiological substrate. The findings from ASD are largely supportive of this and provide further support for the notion that past- oriented and future-oriented cognition are interdependent. The episodic simulation hypothesis is largely concerned the nature of memory, its primary premise being that both episodic memory and episodic future thinking are constructive processes. Thus, it offers little by way of explicit predictions about other domains of cognition. In contrast, self-projection hypothesis suggests explicitly that theory of mind and navigation should also be impaired in any population that has diminished episodic memory. This is also supported by the data from ASD, although whether these additional deficits are the result of a more basic failure in scene construction, or some other unrelated factor, is unclear. As noted above, Hassabis et al. (2007) argue that scene construction is necessary (but not sufficient) for both navigation and ToM. On the one hand, ASD can provide data about the validity of these theories, in that if any of these core cognitive functions is intact in ASD, both theories would be seriously challenged. On the other hand, one of these theories might better explaining the constellation of difficulties seen in ASD. For example, if individuals with ASD showed an undiminished ability to imagine fictitious, non-personal, atemporal scenarios then this would suggest that basic scene construction abilities are intact in ASD and that difficulties in the aspects of cognition described above are (at least partially) due to a specific deficit in self-projection/mental time travel.

Conclusions

Although the findings concerning direct studies of episodic memory and episodic future thinking in ASD are somewhat inconsistent, it does appear that individuals with ASD have difficulties with standard tests of episodic memory and episodic future thinking. The fact that performance on tests of past and future thinking does not appear to be correlated amongst individuals with ASD is consistent with the idea that episodic future thinking depends on the episodic memory system - if the episodic memory system is dysfunctional in ASD, it seems plausible that individuals with the disorder may employ different compensatory processes in each case.

We have argued that studies of prospective memory and planning can provide indirect evidence regarding the future thinking skills of individuals with ASD. Taken together, the research shows that time-based (but not event-based) prospective memory and planning, are significantly impaired in ASD. This potentially provides partial support for the idea that past and future thinking are intrinsically linked. However, although prospective memory and planning are hypothesized to rely on episodic future thinking, this is yet to be robustly demonstrated on an empirical level. Once we know whether or not these abilities are genuinely associated on the behavioural level, the precise theoretical implications of research on prospective memory and planning abilities in ASD will become clearer.

Evidence from ASD also has the potential to differentiate between competing hypotheses concerning the underlying nature of the relationship between past and future thinking. Research on navigation and theory of mind skills is particularly pertinent in this respect. Whilst there is some minimal existing research on navigation in ASD, and abundant evidence research on theory of mind in ASD, what we really need to unpack the issues at hand are studies directly exploring episodic memory, episodic future thinking, navigation, theory of mind, and, crucially, basic scene construction among a common sample of individuals. Indeed, we are currently conducting just such a study. This will allow us to

definitely determine whether associations or dissociation are observed amongst these abilities in both typical individuals and individuals with ASD.

Notes

1. An important caveat is that BA10 is active during a wide variety of psychological tasks, bringing into question the idea that prospective memory and future thinking are specifically associated at the neurobiological level.

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