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Research Report

Theory of mind development can withstand compromised episodic memory development

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ABSTRACT

As humans, we are consciously aware of unobservable mental states, including our own during episodic memory and other people's by having a "theory of mind" (ToM). Episodic memory and ToM are closely related: they share a neural substrate and emerge close in time in ontogenetic development. This relationship is central to prominent child development and cognitive neuroscience theories of ToM, but its causal nature has not been tested empirically. The current study examined whether normal episodic memory development is necessary for normal ToM development. To investigate this, we tested H.C., a young woman with impaired episodic memory development due to early hippocampal damage, on a wide range of ToM measures. H.C.'s performance was indistinguishable from that of controls on all tests of ToM suggesting that, contrary to theoretical claims in the literature, normal episodic memory development and hippocampal function are not essential for the development of ToM.

1. Introduction

Human social life crucially depends on theory of mind (ToM), the ability to reason about another's beliefs, feelings, desires, intentions, and goals (Frith & Frith, 2010). Given the important role that such social processing plays in human interactions, it is not surprising that ToM has been a major area of investigation. It has been central to comparative research, evolutionary theory, developmental psychology, philosophical thought, and clinical practice (Baron-Cohen, Leslie, & Frith, 1985; Carruthers, 1996; Dennett, 1987; Premack & Woodruff, 1978), contributing to social cognitive neuroscience as an enterprise (Frith & Frith, 2010, 2012; Lieberman, 2012a; Mitchell, 2009). Although, humans regularly engage in ToM, the mechanism supporting this ability and how it develops is a topic of continued debate.

Theories of child development propose that episodic memory or the ability to recall past personal experiences may be critical for the development of ToM (Fivush & Nelson, 2006; Nelson, 2009; Robinson & Swanson, 1990). These theories suggest that insight into one's own mental experiences gained through episodic memory development might enable the child to appreciate others' mental states (Robinson & Swanson, 1990) or to realize that others can have a unique perspective on a shared experience (Fivush & Nelson, 2006). Many studies support a close relationship between episodic memory and ToM. For example, in healthy children the two abilities emerge close in time in ontogenetic development and ToM improves with the development of episodic memory (Naito, 2003; Perner & Ruffman, 1995; Perner, Kloo, & Gornik, 2007). Furthermore, both abilities tend to be impaired together in adults with developmental disorders such as high functioning autism and Asperger's syndrome (Adler, Nadler, Eviatar, & Shamay-Tsoory, 2010).

In addition to the close relationship between episodic memory and ToM in development, in healthy adults there is a high degree of overlap in the brain regions recruited during tasks of episodic memory and ToM. Both abilities appear to engage regions that are considered to be part of the "default network" or internally focused processes, including the medial temporal lobe as well as medial prefrontal, medial parietal, and lateral temporal cortex (Buckner & Carroll, 2007; Hassabis & Maguire, 2007; Rabin, Gilboa, Stuss, Mar, & Rosenbaum, 2010; Spreng & Grady, 2010; Spreng, Mar, & Kim, 2009).

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These findings strengthen the view that access to past experiences via episodic memory may be fundamental to ToM (Corcoran, 2000, 2001; Gallagher & Frith, 2003; Goldman, 1992; Gordon, 1986).

Contrary to suggestions from the neuroimaging literature, findings of preserved ToM in individuals with impaired episodic memory due to adult-onset hippocampal damage suggest that hippocampally mediated episodic memory is not necessary for ToM (Rosenbaum, Stuss, Levine, & Tulving, 2007). However, these adult-onset cases experienced normal episodic memory development, which may be critical for ToM to develop (Fivush & Nelson, 2006; Nelson, 2009; Robinson & Swanson, 1990). It is possible that once developed, ToM no longer depends on episodic memory and can be achieved via alternate strategies and neural substrates, such as social semantic memory, which remains intact in the patients. However, the causal nature of this relationship has not been tested empirically, which is surprising given the implications for understanding how ToM develops and why it is vulnerable to a host of psychiatric and neurological disorders.

The current study investigates the integrity of ToM in H.C., a unique young woman with normal intellectual function despite never having developed normal episodic memory as a result of selective hippocampal damage that occurred in the first week of life (Rosenbaum et al., 2011; Vargha-Khadem et al., 2003). We selected a sample of widely used tests of ToM that (1) vary in the degree of cognitive versus affective content, use of narratives, and type of cue used, (2) activate the set of brain regions that support episodic memory (Spreng et al., 2009), and (3) are sensitive to ToM impairment in a variety of patient groups (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Gregory et al., 2002; Stone, Baron-Cohen, & Knight, 1998; Stuss, Gallup, & Alexander, 2001). Findings of intact ToM in H.C. would provide compelling evidence that the development of episodic memory is not necessary for ToM to emerge, informing theories of cognitive development and the resilience of brain function to early disruption.

2. Methods

2.1. Participants

H.C. is a right-handed woman who was 20 years old at the time of testing. She was born prematurely and has reduced bilateral hippocampal volume by approximately 50% relative to healthy controls (see Fig. 1 Hurley, Maguire, & Vargha-Khadem, 2011; see Rosenbaum et al., 2011; Vargha-Khadem et al., 2003 for a detailed neuropsychological profile). Her impairment affects her personal and public event memory more than her personal and general semantic memory (Rosenbaum et al., 2011), which is consistent with other developmental amnesic cases (Gadian et al., 2000). H.C.'s compromised bilateral hippocampal development appears to have precluded normal development of her autobiographical episodic memory. H.C. successfully graduated from a mainstream high school, completed one year of technical college, and was enrolled in a post-secondary culinary program at the time of testing, from which she withdrew after one year. She was engaged to be married at the time of testing.

H.C.'s autobiographical episodic memory impairment has been well-documented by several groups (Hurley et al., 2011; Rosenbaum et al., 2011; Vargha-Khadem et al., 2003). She consistently shows specific impairment on standardized tests of anterograde and retrograde autobiographical episodic memory (see Table 1 for scores on neuropsychological tests). Experimental testing has corroborated a significant autobiographical episodic memory deficit based on a variety of tests with different methods of cueing and scoring (Hurley et al., 2011; Kwan, Carson, Addis, & Rosenbaum, 2010; Rosenbaum et al., 2011). These deficits may extend to her ability to imagine future personal experiences (cf. Hurley et al., 2011; Kwan et al., 2010).

In the current study, H.C.'s performance was compared with that of 17 right-handed, healthy women with no reported history of neurological or psychiatric illness (mean age = 19.33, $SD = 1.24$; mean education = 13.3, $SD = 1.1$). All participants gave informed written consent in accordance with the ethics review boards at York University and Baycrest.

2.2. Materials, procedure, and results

Participants were tested on several standard ToM tasks that are commonly used in patient and neuroimaging studies. The tasks varied in terms of cognitive

Table 1
H.C.'s performance on standardized tests of autobiographical episodic memory.

Standardized test	H.C.'s score
RBMT (raw score)[a]	7 (impaired)
RBMT-Extended (raw score)[b]	10 (impaired)
California Verbal Learning Test-II[c]	
Acquisition (*T*-score)	38
Short delay free recall (*Z*-score)	−4
Long delay free recall (*Z*-score)	−3
Recognition (*Z*-score)	−2
Rey Osterreith Complex Figure (*T*-score)[c]	
Immediate recall	< 20
Delayed recall	< 20
Delayed recognition	22
Wechsler Memory Scale-III (standard score)[b]	
General memory	49
Verbal—Immediate Recall	71
Verbal—Delayed Recall	46
Visual—Immediate Recall	71
Visual—Delayed Recall	59
Delayed Recognition	75
Wechsler Memory Scale—III (scaled score)[c]	
Logical memory I–Immediate recall	4
Logical memory II–Delayed recall	1

RBMT, Rivermead Behavioral Memory Test.
[a] Score reported in Vargha-Khadem et al. (2003).
[b] Scores reported in Hurley et al. (2011).
[c] Scores reported in Rosenbaum et al. (2011).

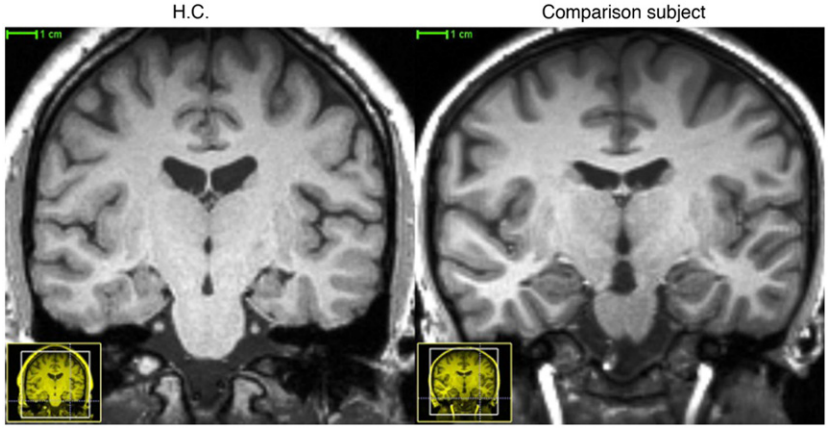

Fig. 1. Selected coronal slices of an MRI scan in H.C. (left) and an age- and sex-matched healthy control (right).