

A Meta-Analysis of Mental Time Travel Impairments in Autism Spectrum Disorders

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Abstract

Individuals with autism spectrum disorders (ASD) have a wide range of cognitive impairments. Mental time travel (MTT) is the ability to mentally re-experience past events and pre-experience possible future events. Studies have shown MTT impairments in individuals with ASD, however, these findings may be confounded by a number of factors including verbal ability to report MTT, factors related to MTT task and demographic factors of participants. The present study provided a meta-analysis on MTT deficits in individuals with ASD and examined the potential moderating variables for these impairments. Twenty-six studies were included, and the participants comprised 667 individuals with ASD and 671 healthy controls. Results showed significant overall MTT impairments (Cohen's $d = -0.95$) in individuals with ASD. Moderator and meta-regression analyses revealed that verbal IQ was significantly related to MTT impairments; type of MTT, type of task, measurement indices of MTT, age of participants, gender ratio and full IQ did not explain the MTT impairments. These findings suggest that MTT is severely impaired in individuals with ASD, verbal IQ contributed to MTT impairments, and task characteristics did not affect the degree of impairments.

Full Text

Preamble

A Meta-Analysis of Mental Time Travel Impairments in Autism Spectrum Disorders

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Abstract

Individuals with autism spectrum disorders (ASD) exhibit a wide range of cognitive impairments. Mental time travel (MTT) is the ability to mentally re-experience past events and pre-experience possible future events. Studies have shown MTT impairments in individuals with ASD; however, these findings may be confounded by a number of factors including verbal ability to report MTT, factors related to MTT tasks, and demographic characteristics of participants. The present study provides a meta-analysis of MTT deficits in individuals with ASD and examines potential moderating variables for these impairments. Twenty-six studies were included, comprising 667 individuals with ASD and 671 healthy controls. Results showed significant overall MTT impairments (Cohen's $d = -0.95$) in individuals with ASD. Moderator and meta-regression analyses revealed that verbal IQ was significantly related to MTT impairments; type of MTT, type of task, measurement indices of MTT, age of participants, gender ratio, and full IQ did not explain the MTT impairments. These findings suggest that MTT is severely impaired in individuals with ASD, that verbal IQ contributes to MTT impairments, and that task characteristics do not affect the degree of impairment.

Keywords: Mental time travel, Autism spectrum disorder, Autobiographical memory, Episodic future thinking, Meta-analysis

1. Introduction

Autism spectrum disorders (ASD) are neurodevelopmental disorders characterized by persistent difficulties in social interaction and communication, restricted repetitive behaviors and/or stereotyped interests, and language impairment (American Psychiatric Association, 2013). Individuals with ASD also exhibit a wide range of cognitive impairments including social cognition and executive function (Kristen, Rossmann, & Sodian, 2014; Lind, Williams, Bowler, & Peel, 2014; Wang et al., 2017). Mental time travel (MTT) is one of the cognitive

functions that enable us to re-experience past personal events (autobiographical memory, AM) and pre-experience possible future events (episodic future thinking, EFT) through mental simulation (Brocas & Carrillo, 2018; Stawarczyk & D'Argembeau, 2015; Suddendorf & Corballis, 1997). MTT is important in daily life because it plays a crucial role in coping, emotion regulation, decision making, and problem solving (Brocas & Carrillo, 2018; D'Argembeau, Renaud, & Van der Linden, 2011; Schacter & Madore, 2016). Impairments have been observed in psychiatric disorders such as schizophrenia-spectrum disorders (D'Argembeau, Raffard, & Van der Linden, 2008), major depressive disorder (Berna et al., 2016; Liu, Li, Xiao, Yang, & Jiang, 2013), post-traumatic stress disorder (Ono, Devilly, & Shum, 2016), and ASD (Crane, Lind, & Bowler, 2013). While most studies in ASD have revealed MTT impairments in these individuals—including generating less specific AM and EFT (Lind, Williams, et al., 2014) and reporting fewer details in AM and EFT (Chaput et al., 2013; Terrett et al., 2013) compared with healthy controls—inconsistent results have also been reported. For example, Crane et al. (2013) did not find AM impairment in individuals with ASD. Ciarra et al. (2018) found that individuals with ASD showed more severe impairments in EFT than in AM, while Lind and Bowler (2010) and Lind, Bowler, and Raber (2014) found that individuals with ASD showed similar impairments in AM and EFT.

Findings on MTT in ASD may be confounded by a number of factors including verbal ability to report MTT, type of MTT (AM or EFT), type of task, indices used to measure MTT, and demographic variables. The present meta-analysis was therefore designed to examine the degree of MTT impairment and the impact of these factors on MTT performance in ASD.

Most MTT measures require verbal report of recalled and imagined scenarios, thus language ability is a basic requirement for MTT performance. Given that language impairment is one of the core deficits in ASD, verbal ability may be related to MTT impairments in these individuals (Marini et al., 2016). Although the majority of studies matched verbal or narrative ability between ASD and control groups (Bang, Burns, & Nadig, 2013; Goddard, Dritschel, Robinson, & Howlin, 2014; Maister, Simons, & Plaisted-Grant, 2013), narrative ability was found to be significantly correlated with EFT performance in both typically developing and ASD children (Marini et al., 2018). However, whether verbal IQ is correlated with MTT impairments in ASD is an important issue that has been under-studied in previous research; the present study examines this issue.

Theoretically, AM and EFT are closely related. Performance on AM and EFT are significantly correlated in healthy populations (Addis, Wong, & Schacter, 2007; D'Argembeau, Raffard, & Van der Linden, 2008; Schacter & Madore, 2016) and in individuals with ASD (Lind & Bowler, 2010). AM and EFT also share similar scene construction (Schacter & Addis, 2007) and self-projection (Lind, Bowler, & Raber, 2014) processes. However, EFT may require additional processes to recombine and reconstruct elements from AM into novel and integrative events that might happen in the future (Gilmore et al., 2018; Schacter

et al., 2007). Whether individuals with ASD show differentiated impairments in AM and EFT remains unclear, and we therefore examine the type of MTT as a moderator in the present meta-analysis.

Studies have adopted different tasks and used different indices when measuring MTT. The commonly used tasks include the cue word task (sometimes referred to as Autobiographical Memory Test) (Crane, Goddard, & Pring, 2009; Crane, Pring, Jukes, & Goddard, 2012; Robinson, Howlin, & Russell, 2017) and the Autobiographical Memory Interview (Crane & Goddard, 2008; Kristen et al., 2014; Tanweer, Rathbone, & Souchay, 2010). In the cue word task, participants are required to generate specific events from personal memories or possible future events related to cue words. The main index used in this task is specificity. A specific event is defined as an event happening at a particular place and time and lasting no more than one day. In the Autobiographical Memory Interview, participants are required to generate personal AM and EFT events during specific life periods. For example, Crane and Goddard (2008) required participants to generate AM from four time periods (before age 5; ages 5 to 11; ages 11 to 16; ages 16 to 21). In this test, the main indices used are the number of details, specificity, and experiential index (e.g., vividness and emotionality) (Chaput et al., 2013; Kristen et al., 2014). Crane et al. (2013) used the Autobiographical Memory Interview and did not find MTT impairments in ASD, while Tanweer et al. (2010) used a cue word task and found that individuals with ASD showed deficits in both AM and EFT. Whether these inconsistent results were due to differences in tasks or indices needs to be examined.

Demographic characteristics of participants such as age and gender have been suggested to significantly affect MTT performance. Abram, Picard, Navarro, and Piolino (2014) found that MTT performance showed an inverted U-shape across the lifespan in healthy participants—that is, it improved from ages 6 to 21 and declined from ages 62 to 81. AM has been studied in individuals with ASD across the lifespan, including children, adolescents, and adults (Ciaramelli et al., 2018; Crane & Goddard, 2008; Goddard, Dritschel, & Howlin, 2014). Adults with ASD generated less detail and fewer specific memories than control groups (Tanweer et al., 2010), while children and adolescents with ASD showed mixed results. Most studies found that ASD children and adolescents generated fewer specific AM or EFT and with fewer details than healthy controls (Goddard et al., 2014a; Hanson and Atance, 2014); however, several studies indicated that these individuals did not exhibit impairments in MTT (Crane et al., 2013; Robinson et al., 2017). In addition, Goddard, Dritschel, Robinson, and Howlin (2014) found that females had better performance (i.e., more details) than males in AM for both ASD and typically developing children.

Taken together, the present study conducted a meta-analysis on MTT in individuals with ASD. In particular, we aimed to examine the impact of verbal ability (indexed by verbal IQ) on MTT in ASD. We also examined the effect of type of MTT, type of task, indices used to measure MTT, and demographic factors such as age, gender, and full IQ on MTT performance in ASD. We hypothesized that

individuals with ASD would show significant MTT impairments, that verbal IQ would be related to MTT impairments, that individuals with ASD would show impairments in both AM and EFT, and that MTT deficits in individuals with ASD would be stable across different tasks and indices.

2.1. Literature search

A literature search was conducted in Web of Science, PubMed, and Elsevier using the following keywords: (autism OR ASD OR Autism Spectrum Disorders OR Asperger OR HFA OR high functioning autism) AND (mental time travel OR past thinking OR AM OR autobiographical memory OR remembering the past OR future thinking OR prospection OR foresight OR future simulation OR imagining the future OR future directed thinking OR imagined future). The literature search covered from 1972 to July 30, [year not specified]. The search was restricted to peer-reviewed papers. A total of 645 potential papers were identified from the literature search, and an additional 31 papers were identified through reference lists from review articles. After excluding irrelevant articles based on title and abstract and removing duplicates, 45 papers remained for further consideration. Studies were included if they met the following criteria: (a) studies were reported in English; (b) studies were not reviews, comments, or meta-analyses; (c) individuals with ASD were diagnosed using formal diagnostic criteria, e.g., International Classification of Diseases (ICD; World Health Organization, 1992); Diagnostic and Statistical Manual of mental disorders (DSM; American Psychiatric Association, 2000, 2013); the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994); the Autism Diagnostic Observation Scale (ADOS; Lord et al., 2000); Autism Diagnostic Observation Schedule-Generic (Lord et al., 2000), Autism Diagnostic Observation Schedule-2nd edition (Lord et al., 2012), and the Asperger Syndrome Diagnostic Interview (ASDI; Gillberg, Gillberg, Rastam, & Wentz, 2001), etc.; (d) studies compared individuals with ASD with healthy controls; (e) studies measured AM or EFT or both; (f) studies reported sufficient data to calculate effect size. For studies that met the previous criteria but lacked sufficient data to calculate effect size, we contacted the authors to provide additional data. If no further data were provided, the studies were excluded from the final analysis. As a result, 26 papers were included in the meta-analysis. The process of literature screening is shown in Fig. 1 [Figure 1: see original paper].

INSERT FIG 1 HERE

2.2. Data extraction

For each included paper, the following data were extracted: First, basic study information such as the first author and publication year. Second, participant information including diagnosis, sample size, mean age, mean full and verbal IQ, and gender ratio. Third, data for calculating effect sizes on group differences in MTT. Means and standard deviations on MTT measures were extracted; if

means and standard deviations were not available, other data that could be used to calculate effect sizes such as t-values and sample size were extracted. Fourth, the type of MTT (AM, EFT) was recorded. Four studies measured both AM and EFT; these papers had an overall effect size calculated by averaging those of AM and EFT for the overall MTT analysis; in the moderator analysis, the effect sizes for AM and EFT were calculated separately (Chisholm et al., 2018; Lind, Bowler, et al., 2014; Raffard et al., 2010). Fifth, the type of task used to measure MTT (cue word task, Autobiographical Memory Interview) was recorded. Two studies used both measures to assess AM; these papers had an overall effect size calculated by averaging those of the two measures; in the moderator analysis, their effect sizes were calculated separately (Crane et al., 2013; Goddard, Dritschel, & Howlin, 2014; Goddard, Dritschel, Robinson, et al., 2014). Sixth, the outcome indices of MTT (number of details/specificity/experiential index¹) were recorded. Four papers provided more than one index for the same type of MTT (Crane, Goddard, & Pring, 2010; Goddard, Dritschel, & Howlin, 2014; Raffard et al., 2010; Robinson et al., 2017), and these papers had an overall effect size; in the moderator analysis, each index was calculated separately. In addition, three studies used nonverbal tests to measure future thinking and could not be classified into these task types and indices; thus these three studies were excluded from these two moderator analyses (Ferretti et al., 2018; Marini et al., 2016, 2018). Two studies used the same participants but adopted different tasks; the average effect size of these two studies (taken as one study) was used in the analyses (Marini et al., 2016, 2018).

¹ Experiential index included different measures such as emotion, sensory details, vividness, importance intensity, etc. A non-weighted average effect size of all the measures was calculated for each study.

2.3. Data analyses

The data were analyzed using Comprehensive Meta-Analysis (version 2.0) (<https://www.meta-analysis.com/>); Cohen's *d* was used as the index of effect size. We first examined the overall impairments of MTT in ASD. We then examined whether MTT deficits in ASD were related to the following variables using moderator analyses or meta-regression: (1) verbal IQ of individuals with ASD; (2) the type of MTT (AM vs. EFT); (3) the type of task (cue word task vs. Autobiographical Memory Interview); (4) the type of outcome indices (number of details vs. specificity vs. experiential index)²; (5) the age period of participants (children vs. adults); (6) the male gender proportion; (7) the full IQ of individuals with ASD.

We reported the heterogeneity of the studies with the *Q* statistic; if *Q* was significant, we adopted the random-effects model to report effect sizes; when *Q* was non-significant, we adopted the fixed-effects model. The moderator analyses adopted the random-effects model. All significance levels were set at $p < 0.05$ (Hedges and Vevea, 1998). Publication bias was examined with the fail-safe *N* analysis, which indicated the number of studies with null results needed to

reject the present significant findings.

² For number of details, we included papers that measured MTT performance with number of details in participants' responses; in addition, papers that calculated the total score of specificity (for example, a specific event was scored 4, an extended event was scored 3, a categorized event was scored 2, a semantic associated event was scored 1, an omission was scored 0, then the total score was added as the index of MTT performance) were also considered as this type (Chaput et al., 2013). For specificity, we included papers that reported the proportion of specific responses or number of specific responses as MTT performance. For experiential index, we included papers that reported either self-report (Crane et al., 2010) or calculated experiential index by experimenters that referenced the narrative (Brown, Morris, Nida, & Baker-Ward, 2012; Crane et al., 2010) about emotion, sensory details, vividness, etc. as MTT performance.

3.1. Overall MTT impairments in individuals with ASD

The final analysis included 26 studies comparing MTT performance between 667 individuals with ASD and 671 healthy controls. Table 1 provides a summary of these studies. The mean effect size (Cohen's d) of MTT is -0.95, with a 95% confidence interval of -0.74 to -1.17, suggesting that individuals with ASD are impaired in MTT with a large effect size (see Table 2 and Fig. 2 [Figure 2: see original paper]). These studies were heterogeneous ($Q = 78.13$, $p < 0.001$). Publication bias analysis revealed that at least 1,571 studies with null results would be needed to reject the present results, which is much larger than the number of studies included in the analysis ($N = 26$), suggesting that publication bias was unlikely to contribute to the significant results.

INSERT TABLE 1 & 2 AND FIG 2 HERE

3.2. Moderator and meta-regression analyses

3.2.1. The effect of verbal ability of ASD individuals

Meta-regression analysis revealed that MTT impairments were significantly related to verbal IQ ($Z = 2.07$, $p = 0.038$) (see Fig. 3 [Figure 3: see original paper]).

INSERT FIG 3 HERE

3.2.2. The effect of the type of MTT³

Results indicated that the moderator effect was not significant ($Q = 1.47$, $p = 0.226$). ASD showed significant impairments in both AM ($d = -0.98$, $p < 0.001$) and EFT ($d = -0.68$, $p = 0.002$) (see supplementary Fig. 1). However, the number of studies on EFT was limited ($N = 7$) and the results should be interpreted with caution.

³ One study (Lind and Bowler, 2010) was excluded from this analysis because it did not report data on AM and EFT separately.

3.2.3. The effect of the MTT task

There was no significant difference between the cue word task and Autobiographical Memory Interview ($Q = 0.73$, $p = 0.390$). ASD showed significant impairments in studies using both the cue word task ($d = -1.02$, $p < 0.001$) and the Autobiographical Memory Interview ($d = -0.81$, $p < 0.001$) (see supplementary Fig. 2).

3.2.4. The effect of the indices of MTT

Individuals with ASD showed similar impairments across the three indices ($Q = 4.17$, $p = 0.125$). These individuals exhibited medium to large effect sizes on all indices (number of details, $d = -1.02$, $p < 0.001$; experiential index, $d = -0.37$, $p = 0.001$; specificity, $d = -0.82$, $p < 0.001$) (see supplementary Fig. 3).

3.2.5. The effect of age period of ASD individuals

Individuals with ASD showed similar impairments in MTT between children and adults ($Q = 0.61$, $p = 0.436$). Both children ($d = -0.90$, $p < 0.001$) and adults ($d = -1.06$, $p < 0.001$) with ASD showed significant MTT impairments (see supplementary Fig. 4 [Figure 4: see original paper]).

3.2.6. The effect of gender ratio and full IQ of ASD individuals

Meta-regression analysis revealed that MTT impairments were not predicted by gender ratio (percentage of male individuals in the ASD group) ($Z = -1.22$, $p = 0.223$) or full IQ ($Z = 0.189$, $p = 0.851$) (see supplementary Fig. 5 [Figure 5: see original paper] & 6).

Considering the small number of studies on EFT, we conducted further moderator and meta-regression analyses limited to AM, with no change in the findings (see supplementary Table 1 and supplementary Fig. 7 [Figure 7: see original paper] - 9).

4. Discussion

The present meta-analysis revealed that individuals with ASD showed impairments in MTT with a large effect size. Moderator and meta-regression analyses showed that verbal IQ was significantly correlated with MTT impairments, while the following variables did not affect the degree of impairments in MTT in individuals with ASD: type of MTT, type of task, indices of MTT, and demographic factors including age, gender ratio, and full IQ.

4.1. Overall MTT Impairments in ASD

The present study revealed a large effect size of MTT impairments in individuals with ASD. Linguistic dysfunction in ASD individuals may contribute to MTT impairments, as our meta-regression results revealed that verbal IQ was significantly related to MTT performance. Most studies examining MTT used verbal paradigms that required participants to describe recalled or imagined scenarios (Ferri, Abel, & Brodtkin, 2018; Lind, Bowler, et al., 2014). Linguistic ability is the basis for verbal report (Ferri et al., 2018; Marini et al., 2018). Linguistic difficulty as a core symptom of ASD manifests at different levels including microlinguistic (e.g., lexical, grammatical) and macrolinguistic (e.g., structure, discourse, narrative) (Boucher, 2012; King, Dockrell, & Stuart, 2014). In a story narrative generation task, individuals with ASD produced less grammatically complex sentences (King, Dockrell, & Stuart, 2014) and more global coherence errors and fewer new elements (Ferretti et al., 2018). Marini et al. (2018) found that impairments in MTT and story narrative generation were related in individuals with ASD. However, linguistic dysfunction could not explain all the MTT impairments. For example, Millward, Powell, Messer, and Jordan (2000) revealed a non-significant correlation between MTT performance and verbal ability in individuals with ASD; individuals with ASD still showed MTT deficits compared to typically developing children after matching verbal ability (Goddard, Dritschel, & Howlin, 2014; Goddard, Dritschel, Robinson, et al., 2014). Moreover, in studies using non-verbal MTT tasks that required participants to make foresight choices instead of describing future scenarios, individuals with ASD still demonstrated MTT difficulties (Ferri et al., 2018; Marini et al., 2016, 2018). Thus, linguistic ability seems to contribute to only part of MTT impairments in individuals with ASD.

Other factors may also contribute to MTT impairments in ASD. Executive dysfunction is likely to impact search strategies for autobiographical memory retrieval. In the self-memory system model proposed by Conway and Pleydell-Pearce (2000), autobiographical knowledge is stored in a hierarchical structure, with lifetime periods at the top level, general events in the middle, and event-specific knowledge represented at the bottom level. When retrieving AM, one of the approaches is through generative search, which accesses the top level of memories first and then searches lower levels for more specific memories, implicating executive resources, as shown by Williams et al. (2007). This viewpoint also receives empirical support from other studies; for example, D' Argenbeau, Ortoleva, Jumentier, and Van der Linden (2010) found significant correlations between executive functions and MTT specificity. Individuals with ASD have been found to show multifaceted executive dysfunction including deficits in planning, inhibition, and monitoring (Hughes, Russell, & Robbins, 1994; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). These impairments may cause the lack of specificity in MTT in ASD.

Individuals with ASD have “weak central coherence,” which means they show detail-focused processing and have difficulty extracting a gist or reconstructing

an intact scene (Happé and Frith, 2006). Thus, when individuals with ASD generate episodic events, they have difficulty integrating separate elements into a coherent context and can only generate less specific events with poorer experiential index (Bowler, Gaigg, & Lind, 2011).

Part of MTT events are related to social communication ability, while ASD individuals have severe social impairments and lack social experiences (Bluck, Alea, Habermas, & Rubin, 2005; Fivush, Haden, & Reese, 2006; Zamoscik, Mier, Schmidt, & Kirsch, 2016). Previous studies demonstrated that individuals with ASD had difficulty sharing narratives in social contexts and did not understand why they needed to share memories with others (Goldman, 2008). Thus, during the task, difficulty in sharing MTT may have contributed to the reduced specificity and fewer details in ASD individuals (Crane and Goddard, 2008).

Self-impairment deficits may also be relevant. When generating MTT events, the self (e.g., self-images, self-beliefs, and personal goals) plays an important role (Bennouna-Greene et al., 2012; Conway, 2005; D' Argembeau et al., 2010; Libby, Valenti, Pfent, & Eibach, 2011). Visual perspective during MTT is a phenomenological aspect of re-experiencing or pre-experiencing autobiographical events and provides a sense of self; it reflects individuals' self-attitude toward their past or future personal events (Potheegadoo, Berna, Cuervo-Lombard, & Danion, 2013). There are two types of visual perspective: field perspective and observer perspective. Field perspective refers to the egocentric reference frame whereby MTT events are viewed from the perspective of the self, while observer perspective refers to a translocation of the egocentric reference frame in which one views the self from an external reference frame in MTT events (Vogelely & Fink, 2003). If a field perspective is adopted in an MTT event, the feelings of re-experience or pre-experience are rated higher than with the observer perspective (McDermott, Wooldridge, Rice, Berg, & Szpunar, 2016); in contrast, if an observer perspective is adopted, less vividness, fewer details, and lower emotional intensity are reported (Rice & Rubin, 2011). Individuals with ASD were found to adopt an observer perspective more often (Lind and Bowler, 2010), thus showing less specificity and fewer details in MTT.

Poor MTT performance has been reported in various clinical populations (Bennouna-Greene et al., 2012; Berna et al., 2016; Ciaramelli et al., 2018; McDonnell, Valentino, & Diehl, 2017). The present meta-analysis included 23 studies, similar to other meta-analyses on MTT impairments in mental disorders. Berna et al. (2016) included 20 studies in a meta-analysis on AM impairments in schizophrenia patients and reported moderate to large effect size impairments ($g = -0.62$ to -1.40). Two meta-analyses on AM were conducted in depression with 14 and 19 studies, with results revealing that patients showed overgeneralized AM ($g = 1.12$, $d = -0.75$) (Liu et al., 2013; Van Vreeswijk & De Wilde, 2004). Hallford, Austin, Takano, and Raes (2018) conducted a meta-analysis involving 19 studies on EFT in psychiatric disorders (including schizophrenia, depression, etc.), with results showing a deficit with large effect sizes in these patients ($g = -0.84$). These results suggest that the

current findings are generally consistent with previous studies.

Regarding the underlying neural mechanisms of MTT impairments, previous studies have indicated that the core network—including medial and lateral frontal cortex, posterior parietal lobe, and medial temporal lobe (MTL) subsystem including hippocampus, parahippocampus, and ventromedial prefrontal cortex—are related to MTT (Addis et al., 2007; Hallford et al., 2018; Schacter et al., 2007). Individuals with ASD showed abnormal structural and functional connectivity in the core network (Duerden, Mak-Fan, Taylor, & Roberts, 2012; Pua, Bowden, & Seal, 2017). These brain abnormalities might underlie MTT impairments in ASD individuals, although further task-based neuroimaging studies are needed to examine this issue.

4.2. The effect of the type of MTT

The present results suggest that individuals with ASD showed impairments with medium to large effect sizes in both AM and EFT, consistent with most previous studies (Brown et al., 2012; Lind, Bowler, et al., 2014; Raffard et al., 2010). Our results showed AM and EFT were impaired to a similar degree, which is inconsistent with the study by Raffard et al. (2010) suggesting that individuals with ASD showed more serious deficits in EFT than in AM.

Regarding the relationship between AM and EFT, several theories have been proposed that can help explain the impairments in individuals with ASD. Scene construction theory proposes that episodic events are coherent scenes involving individuals mentally integrating multiple information sources, such as semantic information and episodic details (e.g., sensory information and contextual details) into a whole spatial scene (Hassabis & Maguire, 2007). This process has no temporal direction, which means scene construction is involved in both AM and EFT. If scene construction is impaired, AM and EFT should show a similar level of impairment. Consistent with scene construction theory, Lind, Williams, et al. (2014) found that ASD showed equal impairments in non-self-relevant scenes, AM, and EFT conditions. They suggested that MTT impairments in ASD could be attributed to difficulties in scene construction.

Buckner and Carroll (2007) proposed that self-projection is the ability to shift self-perspectives in the temporal, spatial, or social domain. Based on the self-projection hypothesis, AM involves projecting oneself back into the past to re-experience past events, and EFT involves projecting oneself into the future to pre-experience possible future events (Suddendorf & Corballis, 1997). If the self-projection ability underlying MTT is impaired, AM and EFT would show similar deficits. Lind, Bowler, et al. (2014) suggested that the impairment in AM and EFT in individuals with ASD might be due to their difficulties in projecting themselves into the past or future. Projecting the self in the spatial and social domain needs to be specifically examined to test this hypothesis.

Schacter et al. (2007) proposed the constructive episodic simulation hypothesis, which suggests that EFT is based on AM, with people retrieving and recombining

ing elements of past events to generate EFT that might happen in the future. Based on this theory, individuals with ASD should show more severe deficits in EFT. The present meta-analysis showed that ASD individuals demonstrated similar impairments in AM and EFT, supporting the scene construction hypothesis and self-projection hypothesis but not supporting the constructive episodic simulation hypothesis. However, further studies are needed, given the limited number of EFT studies in the present meta-analysis.

4.3. The effect of MTT indices

Similar to Miloyan and McFarlane (2018), most studies on MTT used the cue word task and the Autobiographical Memory Interview. Since different tasks usually adopted different indices—that is, the cue word task mainly used specificity, while the Autobiographical Memory Interview mainly used number of details and experiential index—we focus our discussion on the effect of MTT indices. Our results revealed that individuals with ASD showed medium to large effect size impairments on all three main indices, with no significant difference between them.

The present results suggest that MTT deficits in individuals with ASD were universal. Similar results were also found in a meta-analysis on AM impairments in patients with schizophrenia (Berna et al., 2016).

One possibility for why individuals with ASD showed similar impairments across the main indices is that these indices have similar constructs. Previous studies suggested that number of details involves memory specificity (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). Griffith et al. (2012) indicated that specificity and details overlap and suggested that if participants generated less specific memories, they might retrieve fewer details. Moreover, self-reported ease of generating specific memories and details were highly correlated (Ritchie & Skowronski, 2006). We speculated that if a specific event was reported, more details would be generated simultaneously, and experiential feelings might also be stronger.

4.4. The effect of age

The present meta-analysis demonstrated that both children and adults with ASD showed large effect size impairments in MTT. Several factors might contribute to this result. Individuals with ASD showed delayed development in many aspects such as executive function, which plays an important role in MTT at an early stage, and these impairments continued into adulthood (Millward et al., 2000). Further, from a neuroanatomical perspective, studies have shown abnormal brain development trajectories, including decreased grey matter volume in the left inferior frontal gyrus, precuneus, and bilateral temporal lobes (Lainhart, 2015; Mak-Fan, Taylor, Roberts, & Lerch, 2012; Yu, Cheung, Chua, & McAlonan, 2011) and abnormal brain activations in the cingulate cortex and superior temporal gyrus during cognitive tasks (Herrington et al., 2007; Lee et

al., 2009; Schmitz et al., 2008; Williams et al., 2006) in both children and adults with ASD. Given that these are core regions involved in MTT, longitudinal studies from childhood will help inform the development of these deficits.

4.5. The effect of gender ratio and full IQ

The present results demonstrated that MTT impairments in individuals with ASD did not correlate with gender ratio or full IQ. However, ASD is more prevalent in males (Christensen, Baio, & Braun, 2018; Ferri et al., 2018), and the limited range of gender ratio (50% to 100%) may partly explain the results. Moreover, our results were consistent with previous studies finding no gender difference in AM impairments (Bang et al., 2013; Crane et al., 2009). In contrast, Goddard, Dritschel, and Howlin (2014) found that female ASD individuals generated similar specificity of AM as healthy controls, while male ASD individuals generated less specificity in AM. Further studies are needed to examine this issue. The present results did not show a relationship between MTT impairments and full IQ, which might be because all studies included in the meta-analysis were conducted in high-functioning autism. Thus, further studies are needed in low to medium functioning individuals with autism.

4.6. Limitations and implications

There are several limitations in the present study. The number of studies on EFT in individuals with ASD was limited, so the results of the moderator analysis on type of MTT should be interpreted with caution. Further, although the moderator analyses we conducted did not show significant results, there was significant heterogeneity among the studies. This may be caused by other potential factors that we did not identify, for example, the remoteness of the events generated. Previous studies suggested that individuals with ASD reported fewer specific and less accurate AM from remote time periods than from recent time periods (Bruck et al., 2007; Goddard et al., 2014a). However, when dividing the time period into remote or recent, the criteria varied from study to study, making it difficult to conduct a moderator analysis.

Despite these limitations, the present study has implications. MTT is important in daily life, and several studies have shown that strategies to improve MTT also benefit problem solving, emotion regulation, optimism, and well-being in the general population (Jing, Madore, & Schacter, 2016; Peters, Flink, Boersma, & Linton, 2010). Studies have also been conducted in clinical groups; for example, interventions such as event-specific memory training or autobiographical memory training could improve MTT ability in schizophrenia patients (Blairy et al., 2008; Chen et al., 2017; Ricarte, Hernandez, Latorre, Danion, & Berna, 2014), could improve pleasure experience in patients with anhedonia (Favrod, Rexhaj, Nguyen, Cungi, & Bonsack, 2014), and reduce depressive symptoms in patients with depression (Vilhauer et al., 2012). MTT impairment in individuals with ASD was related to the severity of their core symptoms including restricted

repetitive behaviors and reciprocal social interaction (Ciaramelli et al., 2018), and theory of mind deficits (Adler, Nadler, Eviatar, & Shamay-Tsoory, 2010; Crane, Goddard, & Pring, 2011). Further studies need to explore methods to improve MTT ability in individuals with ASD and examine whether this could improve their core deficits.

4.7. Conclusion

The present meta-analysis demonstrated that individuals with ASD had severe impairments in MTT. Verbal IQ was related to MTT impairments. Furthermore, they showed similar levels of impairment in AM and EFT. The MTT tasks, indices, age of participants, gender, or full IQ did not affect the MTT impairments in individuals with ASD.

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Contributors

JY and YW designed the study. JY, XQ, and LJ conducted literature searches. JY conducted the statistical analysis and wrote the first draft of the manuscript. JC and YW revised the manuscript extensively. CP and RC provided insightful comments and improved the manuscript. All authors contributed to and have approved the final manuscript.

Conflict of interests

None.

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Table 1 Descriptions of studies included in the meta-analysis

Table 2 MTT impairments in individuals with ASD

Fig. 1 Flow diagram of the article selection.

Fig. 2 Forest plot (left panel) and funnel plot (right panel) of the overall MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals (left panel).

Fig. 3 Meta-regression of verbal IQ predicting MTT impairments in individuals with ASD.

Supplementary Fig. 1 Forest plot of the effect of the type of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.

Supplementary Fig. 2 Forest plot of the effect of the task on MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.

Supplementary Fig. 3 Forest plot of the effect of the indices of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.

Supplementary Fig. 4 Forest plot of the effect of the age period of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.

Supplementary Fig. 5 Meta-regression of gender ratio predicting MTT impairments in individuals with ASD.

Supplementary Fig. 6 Meta-regression of IQ predicting MTT impairments in individuals with ASD.

Supplementary Fig. 7 Meta-regression of gender ratio predicting AM impairments in individuals with ASD.

Supplementary Fig. 8 Meta-regression of IQ predicting AM impairments in individuals with ASD.

Supplementary Fig. 9 Meta-regression of verbal IQ predicting AM impairments in individuals with ASD.

Supplement Table 1 AM impairment in individuals with ASD

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv – Machine translation. Verify with original.