Time perception and its relationship to memory in Autism Spectrum Conditions

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Abstract

Timing is essential for the development of cognitive skills known to be impaired in Autism Spectrum Conditions (ASC), such as social cognition and episodic memory abilities. Despite the proposal that timing impairments may underpin core features of ASC, few studies have examined temporal processing in ASC and they have produced conflicting results. The present study first addressed discrepancies between previous experiments before testing the assumption that timing impairments may underpin key aspects of autism, by relating differences in temporal processing in the ASC group to memory abilities. Errors in duration reproduction in high functioning children with ASC were observed for the shortest and longest duration tested. While the former was due to attentional factors, the latter was due to deficient timing related to atypical episodic memory processing. These findings suggest that temporal processing abilities play a key role in the poor development of both social cognition and episodic memory abilities associated with ASC.

Introduction

Evidence from clinical accounts suggests that temporal processing may be impaired in Autism Spectrum Conditions (ASC). Individuals with ASC have been documented to have difficulties with comprehending the passage of time, and this is often linked with anxiety and behavioural problems surrounding issues of the timing and temporal order of everyday events (Wing, 1996). Furthermore, evidence from several cognitive domains has found that individuals with ASC are poorer at tasks with a temporal processing requirement than those requiring the processing of static stimuli. For example, individuals with ASC perform more poorly on intelligence measures that have a temporal dimension or require sequential processing compared to those involving static stimuli and simultaneous presentation (Kaufman & Kaufman, 1983; Lincoln, Allen & Kilman, 1995). These anecdotal and research observations have led to the suggestion that a defective timing system may be a core feature of ASC (Boucher, 2001).

Research into typical development reveals the importance of intact timing capabilities to children’s development. For example, timing mechanisms play a key role in the development of social cognition. Early mother–child interactions in babies and infants, such as social turn-taking and pre-verbal protoconversation, all rely on highly sensitive timing mechanisms (see Trevarthen & Aitken, 2001, for review). Babies as young as 6 weeks of age are sensitive to the specific timing of maternal interaction relative to their own gestures and vocalizations; studies using delayed video footage show that infants become distressed when they are shown video feedback of temporally non-contingent maternal interaction (Nadel, Carchon, Kervella, Marcelli & Reserbat-Plantey, 1999). Developmental studies of ASC reveal that interactive turn-taking in young infants, thought to be a demonstration of intact social timing abilities, can reliably distinguish between those with autism and those that are typically developing even before 2 years of age (e.g. Wimpory, Hobson, Williams & Nash, 2000). An impairment in social turn-taking in infants diagnosed with ASC may be caused by an early-emerging deficit in temporal processing; such a deficit may therefore play an important role in later emerging impairments in social development (Boucher, 2001).

Additionally, temporal abilities may play an important role in children’s development of social referencing and joint visual attention, which first appear in typically developing infants towards the end of the first year of life and during the second. Sensitive timing mechanisms, and attention to temporal information, are essential to detect the temporal contingency of joint behaviours towards objects in the environment, which underlie the development of social concepts such as self-other intentionality and theory of mind (Barresi & Moore, 1996; Gergely & Watson, 1999). Infants later diagnosed with ASC have been found to be impaired in social referencing, both...
looking significantly less often at their caregiver when in an uncertain situation, and not utilizing information provided by the caregiver to guide their actions (Sigman & Kasari, 1995). Infants with ASC also show significantly less joint visual attention than typically developing infants, and the extent to which it is reduced correlates with the number of autistic characteristics they display (Naber, Bakermans-Kranenburg, van IJzendoorn, Dietz, van Daalen, Swinkels, Buitelaar & van Engeland, 2008). Given that socio-cognitive impairment is diagnostic of ASC, it may be the case that an underlying, early-emerging deficit in temporal processing, or poor attention to temporal information, may play a vital role in compromising typical early social development in this group.

Successful development of the sociocognitive system is particularly important for episodic memory abilities of the developing infant. The ability to episodically remember personally experienced past events requires an understanding of social concepts, such as a concept of ‘self’ as differentiated from ‘other’ (Conway & Pleydell-Pearce, 2000; Tulving, 2001). This advanced concept is built on more basic sociocognitive structures obtained through ongoing social interaction in early childhood, in which sensitive timing is crucial. For example, the concept of self as distinct from other stems from the early ability to detect specific temporal contingencies and non-contingencies in the social environment (see Rochat, 2001, for review). The personal event memories of individuals with ASC appear to be lacking in the ‘self’ component, and do not show the typical memory advantage of self-involved events (Baker-Ward, Hess & Flannagan, 1990; Hare, Mellor & Azmi, 2007). These characteristics of event memories in ASC are consistent with the notion that a temporal impairment underpins both differences in episodic memory and sociocognitive development in ASC.

Temporal processes are also involved more directly in the development of episodic memory. Episodic memories are characterized by their contextual specificity; they can contain rich perceptual and emotional details, and have a specific spatiotemporal context. Intact timing mechanisms are essential for the successful encoding of both temporal and non-temporal context. The ability to detect and encode temporal contingencies between features of the environment enables the binding between items and context in memory. This allows a coherent, detailed representation of an event to be stored and retrieved. As infants mature, they are increasingly able to encode both temporal and non-temporal context with their memories for events, and this results in a developmental shift away from general, script-like memories to temporally specific, contextually rich episodic representations. If temporal processing is impaired in ASC, their episodic memory system would be expected to be under-developed. Indeed, analysis of the event memory of individuals with ASC reveals an impairment in specific event memory, with an atypical reliance on more general, temporally non-specific representations of events (Crane & Goddard, 2008). In these respects, the event memory of individuals with ASC can mirror that of younger typically developing children before episodic memory has developed fully.

While the processing of temporal information is crucial for the development of episodic memory, the relationship is bidirectional in the sense that episodic memory is critical for making judgements about temporal information. Many everyday situations require us to make explicit temporal judgements based on the duration of events stored in episodic memory. For example, to judge when the kettle may have finished boiling, or assess which of two routes to work takes the shortest time, duration information must be directly retrieved, or inferred, from episodic memory. Additionally, we often need to make judgements on the temporal order of events, for example recalling which of two rooms we entered first and which second when searching for a lost item; this information must also be retrieved from episodic memory. With development of these temporal memory abilities, children begin to be able to time their behaviours and expectations to match duration and order representations of previously experienced events, and correspondingly their complex planning abilities mature (Kodituwakku, Farmer, Shaw & Yeo, 1994).

Since episodic memory plays a key role in making temporal judgements, a deficient timing system in ASC would result in poor performance on tasks requiring the direct retrieval of temporal information from memory. In support of this, it has been found that individuals with ASC perform poorly on memory tasks requiring them to directly retrieve, or infer, temporal information from episodic memory; these include judgements on temporal order and recency discrimination (Bennetto, Pennington & Rogers, 1996).

Given that a deficit in temporal processing may play a key role in compromising development of both episodic memory abilities and sociocognitive skills in ASC, there has been surprisingly little research examining time perception in this group. Only five studies have examined time perception in ASC directly, and there are no studies that address the question of the importance of temporal processing in cognitive impairments in ASC. Furthermore, the five assessments of temporal processing have produced conflicting results; three studies have claimed impairments (Gowen & Miall, 2005; Martin, Poirier & Bowler, 2010; Szlag, Kowalska, Galkowska & Poppel, 2004), one has claimed intact performance (Mostofsky, Goldberg, Landa & Denckla, 2000), and one has claimed superior performance in one measure (Wallace & Happé, 2008). This may partly reflect the wide range of different measures employed to investigate time perception (see Bindra & Waksberg, 1956, for review). Common time perception measures include estimation, production and reproduction tasks. In an estimation procedure, a participant is exposed to a duration and asked to verbally estimate the duration using seconds and minutes. In a standard production paradigm, the participant is asked...
to produce (by means of a ‘start’ and ‘stop’ signal, for example) a specific duration given in seconds or minutes. In a reproduction procedure, the participant is exposed to stimuli of varying durations and these have to be reproduced, again usually by means of a ‘start’ and ‘stop’ response of some kind.

The study by Szelag et al. (2004) used a reproduction procedure, in which children reproduced durations of between 1 second and 5.5 seconds. The children with autism showed significant impairments, producing durations of roughly 3 seconds on every trial, independent of what the actual test duration was. Gowen and Miall (2005) used a ‘rhythm continuation’ procedure which required the children to tap rhythmically, reproducing intervals of 400 to 800 ms. They found the ASC group to be less accurate and more variable in their responses than the typically developing group. The study by Martin et al. (2010) extended these findings to adults with high-functioning ASC. They reproduced target durations of 0.5 to 4.1 seconds, and were found to be impaired relative to a comparison group; they reproduced significantly shorter durations for target durations of 1.7 seconds and above.

The study by Mostofsky et al. (2000), that found no impairment, used a temporal generalization procedure where two successive temporal durations were compared. The experiment was designed to identify the shortest difference in duration that the participants could perceive, and therefore was concerned with the perception of time in the milliseconds range. Finally, the study by Wallace and Happé (2008) claimed to find no deficit in time perception in ASC using three different measures: reproduction, estimation and production. They tested a wide range of durations, from 2 to 45 seconds. Furthermore, the performance of the ASC group in the reproduction task was actually found to be superior to that of the typically developing group.

The variety of measures employed in these five studies may partly explain the lack of consensus in their conclusions. It is thought that different study procedures marshal different cognitive processes in addition to pure ‘time perception’ and therefore results obtained using different measures may not be directly comparable (see Bindra & Waksberg, 1956; Zakay & Block, 1997, for review). For example, estimation and production methods rely on a level of knowledge and experience of seconds and minutes as the formal culturally defined divisions of time, whereas the reproduction procedure is free of this confound. Reproduction is also thought to be the measure least susceptible to effects of spacing, order, range and extraneous stimuli (Richards, 1964). However, the reproduction procedure relies more heavily on memory processes than other methods, as a representation of the target duration must be held on-line to enable the duration to be reproduced (Shaw & Aggleton, 1993).

In addition, each study investigating time perception in ASC has looked at a different range of durations. It is thought that the perception of different durations is mediated by distinct brain mechanisms, and therefore studies that have investigated a restricted range of durations may present a limited picture of time perception in ASC. Durations shorter than around 1 second are thought to be processed sub-cortically, possibly by structures such as the cerebellum (Jueptner, Rijntjes, Weiller, Faisst, Timmann, Mueller & Diener, 1995; Mangels, Ivry & Shimizu, 1998). Representations of longer durations can be processed cortically, and durations up to roughly 30 seconds are thought to be reliant on short-term and working memory mechanisms (Baudouin, Vanneste, Isingrini & Pouthas, 2006; Jueptner et al., 1995; Mangels et al., 1998; Mimura, Kinsbourne & O’Connor, 2000; Perbal, 2003; Pouthas & Perbal, 2004). Durations longer than around 30 seconds are beyond the capacity of short-term memory stores, and therefore may instead be mediated by episodic memory structures (Mimura et al., 2000; Nichelli, Venneri, Molinari, Tavani & Grafman, 1993; Richards, 1973; Schmitter-Edgecombe & Rueda, 2008).

There are several other possibilities for the discrepancies in results between studies. For example, previous studies into time perception in ASC have been direct, explicit tests where it is relatively easy to direct full attention to temporal information. When encoding duration information during an event in a natural setting, there will be a large amount of more salient information being encoded which can distract from temporal information. Individuals with ASC often perform better in closed-task laboratory situations where variables are controlled and limited than they do in a real-world analogue of the task, with few external constraints. Such a discrepancy in performance between lab and naturalistic tasks has been discussed in reference to both the domain of social reasoning (Klin, Jones, Schultz & Volkmar, 2003) and executive functioning (Kenworthy, Yerys, Anthony & Wallace, 2008). Similarly, it may be possible that some studies which have used highly constrained procedures have not thus allowed the opportunity to observe any deficit in temporal processing that occurs in real-world settings.

Nonetheless, there are studies that demonstrate temporal processing impairments in ASC using tasks that allow focused attention to the temporal information in the task. However, none of these studies employed a procedure that prevented chronometric counting in the studies. Counting is readily and spontaneously employed in typically developing children over 8 years old in explicit laboratory-based timing tasks (Droit-Volet & Wearden, 2001), and its use greatly improves accuracy in tasks measuring perception of durations in the seconds range (Clément & Droit-Volet, 2006). As yet, no research has investigated the propensity for individuals with ASC to employ a counting strategy in timing tasks, and whether the development of this propensity differs from that of typically developing children. Therefore, chronometric counting represents a source of uncontrolled variability in past studies investigating temporal processing in ASC.

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There were two aims of the current study. The first was to assess temporal processing in children with and without ASC in a procedure that addressed the methodological concerns associated with previous research in temporal processing in ASC. Our experiments therefore employed a reproduction paradigm in order to enable comparison with a number of past studies, and, to improve ecological validity and make the task more naturalistic, a concurrent verbal task was employed during the temporal reproduction tasks (as in Schmitter-Edgecombe & Rueda, 2008; see also Stubbs, Dreyfus, Fetterman, Gibbon & Allan, 1984). This meant that a ‘filled’ duration was reproduced. Additionally, the verbal nature of the task prevented chronometric counting, further enhancing its applicability to the temporal processing demands found in everyday life, and reducing error associated with group differences in the employment of a counting strategy. A wide range of durations from 0.5 seconds to 45 seconds were tested, to investigate time perception mediated by sub-cortical structures, and both short- and long-term memory in both typically developing children and those with ASC.

Having established a temporal processing difficulty in the group with ASC in Experiment 1, our second aim was addressed in Experiment 2, which examined whether differences in temporal performance in ASC were related to memory abilities. As temporal processing and memory development are closely interlinked, we predicted that good temporal processing would be associated with better memory abilities. As discussed, individuals with ASC have been reported to have a specific deficit in episodic memory. Given that episodic memory is thought to be related to temporal processing at long durations, we expected temporal processing at long durations to be impaired in the ASC group, and the level of this impairment to be associated with level of episodic memory deficit. To test these predictions, measures of short- and long-term memory were taken to elucidate the role of mnemonic processes in time perception.

Experiment 1

Method

Participants

Twenty-one children with ASC (the ASC group) and 21 typically developing children (the TD group) participated in the study. The children were aged between 8 and 13 years old. Diagnoses for the ASC group (20 boys, one girl) were made by an experienced, trained independent clinician and based on the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter & Le Couteur, 1994), which focuses on the following three areas: communication and language, reciprocal social interaction, and repetitive and restricted behaviours. All children met full criteria for autism, and had scored above cut-off on all three domains. None of the children were currently taking any medication. Children with additional psychiatric diagnoses were excluded, as established by referring to Statements of Special Educational Needs. All children in the ASC group attended Specialist Autism Schools. The children in the TD group (13 boys, eight girls) had no known psychiatric diagnoses (as established by both parental report and by referring to any Statements of Special Educational Needs) and attended mainstream state primary and secondary schools. They were matched with the ASC group on chronological age, verbal ability and non-verbal IQ. Verbal ability was assessed using the British Picture Vocabulary Scale (BPVS; Dunn, Whetton & Pintilie, 1988) which correlates well with more complex language tasks, such as syntax (McCann, Peppe, Gibbon, O’Hare & Rutherford, 2007). Non-verbal IQ was measured using Raven’s Standard Progressive Matrices (RPM; Raven, Court & Raven, 1977). These data are summarized in Table 1.

Informed parental consent was obtained for each child and the study was approved by the Cambridge Psychology Research Ethics Committee.

Tasks and procedure

RPM and BPVS were administered according to the standardized testing procedures. The BPVS was scored using published norms (Dunn et al., 1988) to obtain standardized scores independent of age.

The time reproduction task was conducted on a 14-inch LCD Acer laptop running Microsoft Windows XP. It was programmed using DMDX software (Forster & Forster, 2003) which has highly accurate timing capabilities. Temporal durations were demonstrated visually, to allow a concurrent verbal task to be employed. A visual stimulus on the screen, a blue square, was presented to the participants for a fixed duration. After a 1-second delay, they were then asked to reproduce the temporal duration demonstrated to them by deciding when to terminate a subsequent visual stimulus, a purple square, using a key-press. Seven durations were tested: 0.5, 1, 2, 4, 10, 30 and 45 seconds, and a 2.5-second interval separated each trial. Duration presentation was randomized, and each target duration was tested twice. This number of repeated trials was constrained by the large number of intervals tested and the relatively long intervals involved. Before the experiment commenced, each participant received verbal instruction followed by three verbally guided practice trials to ensure that the task was understood.

To prevent chronometric counting and to improve the task’s relevance to the timing demands of everyday life, a verbal concurrent task was employed. Participants listened to an audio recording of common words via headphones on a portable audio player, and repeated every word they heard out loud. This task was carried out continuously during both the exposure and reproduction phases of the time reproduction task. It was
ensured that there was a mix of different lengths of words and delays between each word to prevent non-verbal rhythmic timing methods being employed. All words had an Age of Acquisition score of below 5 years old (Stadthagen-Gonzalez & Davis, 2006) and were easily repeated and pronounced by all children. Verbal shadowing responses were recorded on a digital voice recorder for later analysis. The total number of words presented ranged from 145 to 160, depending on the duration of each participant’s responses. Accuracy of verbal shadowing was very high; only five children with ASC and four typically developing children failed to repeat one of the words during the verbal concurrent task. This reflects a minimum accuracy score of 99.84% for the ASC group and 99.87% for the TD group. Given the very high accuracy and negligible group differences, it was concluded that both groups were performing the verbal concurrent task equally successfully.

General procedure

Children completed two separate testing sessions; one of roughly 45 minutes in duration and one of 10 minutes. The sessions took place individually in quiet rooms at their school during the school day. The RPM and BPVS were completed during the first session, and the time reproduction task was carried out in the second session, which was conducted on a different day.

Results

For all analyses, the alpha level was set at .05 and all tests were two-tailed. The statistical tests were carried out using PASW 18.x statistical software.

A ‘proportion error’ score was calculated to assess performance on the time reproduction task. The duration of the participant’s response (in milliseconds) was subtracted from the target duration for each trial, to obtain a mean absolute difference. This score was then divided by the target duration to obtain error as a proportion of the target duration. This enabled performance on different trial durations to be directly compared within subjects.

The error scores were subjected to a logarithmic transform prior to parametric analysis, to correct positive skew. After transformation, all variables were analysed using Kolmogorov-Smirnoff tests and did not show significant deviation from normality (p > .05 for all variables).

The transformed error scores were analysed using a 2 (group: ASC vs. TD) by 7 (duration: 0.5s vs. 1s vs. 2s vs. 4s vs. 10s vs. 30s vs. 45s) mixed ANOVA. There was a main effect of group, F(1, 40) = 9.26, p < .01, ηp2 = .19, but not duration, F(6, 240) = 1.43, p = .20, ηp2 = .03. There was also a Group × Duration interaction, F(6, 240) = 2.36, p = .03, ηp2 = .06.

Error scores for each target duration were then analysed using independent t-tests. The ASC group had a significantly higher error score than the TD group for short target durations of 0.5 seconds (MASC = 1.35 (SD = 2.32), MTD = 0.44 (SD = 0.72); t(40) = −2.27, p = .03, ηp2 = .11), 1 second (MASC = 0.75 (SD = 0.97), MTD = 0.24 (SD = 0.21); t(40) = −2.69, p = .01, ηp2 = .15) and 2 seconds (MASC = 0.59 (SD = 0.61), MTD = 0.26 (SD = 0.16); t(40) = −2.11, p = .04, ηp2 = .10). They also had a significantly higher error score than the TD group for the longest target duration of 45 seconds, MASC = 0.44 (SD = 0.24), MTD = 0.20 (SD = 0.16); t(40) = −3.80, p < .01, ηp2 = .27. The groups did not differ significantly in their performance on the intermediate target duration trials of 4, 10 and 30 seconds (all p-values > .05). Group differences are illustrated in Figure 1.

Each target duration was tested twice to give a measure of response variability between the first and second

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Table 1  Mean age and psychometric scores for the typically developing (TD) group and the Autism Spectrum Condition (ASC) group. BPVS is British Picture Vocabulary score, RPM is Raven’s Progressive Matrices score, and d is the measure of effect size Cohen’s d.

<table>
<thead>
<tr>
<th>Measure</th>
<th>TD group (N = 21)</th>
<th>ASC group (N = 21)</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Chronological age (years)</td>
<td>10.7</td>
<td>0.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Standardized BPVS</td>
<td>111.3</td>
<td>11.6</td>
<td>102.0</td>
</tr>
<tr>
<td>RPM</td>
<td>38.3</td>
<td>8.0</td>
<td>40.1</td>
</tr>
</tbody>
</table>

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trial of the same target duration. This variability is taken to reflect attentional factors (Brown, 1997; Mullins, Belgrove, Gill & Robertson, 2005; Pouthas & Perbal, 2004). We therefore analysed intra-individual variability of responses in order to assess whether the differences observed in the main ANOVA may be due to attentional differences between the two groups rather than time perception differences. A variability score was obtained for each participant for each target duration by calculating the difference between the proportion error scores of the first and second trials of the same target durations. The variability scores were transformed with a logarithmic transform, which resulted in a normal distribution as assessed by Kolmogorov-Smirnoff tests (all p-values < .05).

The transformed variability scores were analysed using a 2 (group: ASC vs. TD) by 7 (duration: 0.5s vs. 1s vs. 2s vs. 4s vs. 10s vs. 30s vs. 45s) mixed ANOVA. There was a main effect of group, F(1, 40) = 7.74, p = .01, η²p = .16, with the ASC group producing significantly more variable responses than the TD group, MASC = 0.86 (SD = 0.70), MTD = 0.39 (SD = 0.20). There was also a main effect of duration, F(6, 240) = 5.18, p < .01, η²p = .12. No interaction was present, F(6, 240) = 1.36, p = .23, η²p = .03.

A correlational analysis was then employed to investigate the role of intra-individual variability in overall error of reproduction, using Pearson’s Product Moment correlations. A correlation between variability and error was conducted for each duration and each group. In the ASC group, variability scores correlated with reproduction error only for short and medium durations; 0.5 seconds (r = .66, p < .01), 1 second (r = .77, p < .01), 2 seconds (r = .57, p = .01), 4 seconds (r = .49, p = .02) and 10 seconds (r = .50, p = .02). The error scores for long target duration trials (30s and 45s) did not significantly correlate with variability scores (p-values < .05).

Conversely, in the TD group variability did not significantly correlate with reproduction error at any target duration (p-values < .05) with the one exception of a negative correlation at 30s (r = −.56, p = .01), implying that with greater variability between first and second response, the more accurate was temporal reproduction. It seems highly unlikely that poor attention (as indicated by high variability) could result in more accurate performance at this specific duration only, and thus is likely to be an anomalous result.

### Experiment 2

Experiment 1 revealed that the ASC group were impaired in the reproduction of short durations (of up to 2 seconds), and that this impairment was associated with attentional variability. The ASC group were also found to be impaired in the reproduction of the longest duration tested, 45 seconds. Unlike performance at short durations, performance at 45 seconds did not appear to be related to attentional variability, and we speculated that reproduction at this duration was instead related to episodic memory abilities. A second experiment was carried out to investigate this suggestion; the role of both short- and long-term memory in the temporal reproduction deficits of ASC was assessed.

### Method

#### Participants

Fifteen children with ASC (referred to as the ASC group) and 15 typically developing children (referred to as the TD group) participated in the study. No child had participated in the last experiment. The children were aged between 8 and 13 years old. Method of diagnosis and participant exclusion criteria were exactly as used in Experiment 1. All children in the ASC group (15 boys) attended Specialist Autism Schools, met full criteria for autism, and had scored above cut-off on all three domains. None of the children were currently taking any medication. The children in the TD group (11 boys, four girls) attended mainstream state primary and secondary schools. They were matched with the ASC group on chronological age, verbal mental age and non-verbal IQ. As in Experiment 1, verbal ability was assessed using the British Picture Vocabulary Scale (Dunn et al., 1988), and non-verbal IQ was measured using Raven’s Standard Progressive Matrices (Raven et al., 1977). These data are summarized in Table 2.

Informed parental consent was obtained for each child and the study was approved by the Cambridge Psychology Research Ethics Committee.

### Table 2  Mean age and psychometric scores for the typically developing (TD) group and the Autism Spectrum Condition (ASC) group. BPVS is British Picture Vocabulary score, RPM is Raven’s Progressive Matrices score, and d is the measure of effect size Cohen’s d

<table>
<thead>
<tr>
<th>Measure</th>
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<th>ASC group (N = 15)</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Chronological age (years)</td>
<td>11.2</td>
<td>1.2</td>
<td>11.8</td>
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<tr>
<td>Standardized BPVS</td>
<td>115.8</td>
<td>8.7</td>
<td>105.6</td>
</tr>
<tr>
<td>RPM</td>
<td>40.0</td>
<td>5.9</td>
<td>39.7</td>
</tr>
</tbody>
</table>

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Tasks and procedure

The Raven’s Matrices and the BPVS were administered according to the standardized testing procedures. The BPVS was scored using published norms (Dunn et al., 1988) to obtain standardized scores independent of age.

For the time reproduction measure, the same task and method were used as in Experiment 1. Verbal responses during the concurrent task were recorded on a digital voice recorder for later analysis. As in Experiment 1, the total number of words presented ranged from 145 to 160, depending on the duration of each participant’s responses. Accuracy of verbal shadowing was again very high; only four children with ASC and six typically developing children failed to repeat one of the words during the verbal concurrent task. This reflects a minimum accuracy score of 99.82% for the ASC group and 99.72% for the TD group. Given the very high accuracy and negligible group differences, it was concluded that both groups were performing the verbal concurrent task equally successfully.

A visuo-spatial delayed match-to-sample task (a task frequently used with ASC participants; for example see Barth, Fein & Waterhouse, 1995) was used to assess visuo-spatial short-term memory. This task was a variant of the Sternberg Task (e.g. Sternberg, 1966). The task contained 15 trials. In each trial, a 3 × 2 grid was displayed on the screen, with either three, four or five shapes filling some of the areas made by the grid. The shapes were simple and easily discriminable; they consisted of a square, a circle, a triangle, a star, and a cross, and each had a distinct colour. The shape array was displayed for 2 seconds and was followed by an interval of 3 seconds, which was then replaced by a ‘question screen’; this consisted of one of the previously shown shapes in the centre of the grid with a question mark inside it. The child was instructed to point to the square where they remembered the shape appearing in the previous array. They were advised to guess if they could not remember or were uncertain. Responses were marked on a score sheet by the experimenter after each trial before progressing to the next. Before the task began, the children were shown a verbally guided practice trial. All children responded correctly on this trial and therefore progressed immediately to the main task.

A phonological word-span task was used to assess phonological short-term memory. This task was carried out verbally by the experimenter, and was based on a commonly used verbal memory span paradigm (e.g. Archibald & Gathercole, 2006; Gathercole & Adams, 1994; Hick, Botting & Conti-Ramsden, 2005). Lists of words were read out to the participant, and they were instructed to repeat the words back in the order they were presented. All words were two syllables, and had a maximum age of acquisition of 5 years (Stadthagen-Gonzalez & Davis, 2006). The trials consisted of blocks of three lists of the same length. When one block was completed, the participant then attempted the next block, which contained lists that were one word longer than the last. A block was seen as completed when two of the three lists were repeated in the correct order, without any omissions. When a block was not completed, the task ended. All participants began on a three-word list block. The successfully repeated lists and blocks were marked on a score sheet by the experimenter during the task.

A long-term memory free recall task (i.e. Hermelin & O’Connor, 1967) was used to assess episodic memory. Fifteen semantically unrelated words were presented to the participant on a computer screen. Each word was presented individually for 3 seconds, with a 1-second gap between presentations. At the end of the presentations, participants completed a non-verbal ‘filler’ task to eliminate recency effects. This took the form of a simple maze game, and took on average 4 minutes. The duration of the filler task did not differ significantly between groups, $M_{TD} = 238.6s$ ($SD = 62.8$), $M_{ASC} = 237.9s$ ($SD = 39.3$); $t(28) = 0.04$, $p = .97$. Participants were then asked to recall as many of the words as possible out loud, in any order. Responses were recorded on a digital voice recorder for later analysis.

General procedure

Children completed two separate testing sessions of roughly 45 minutes each. The Raven’s Matrices and the British Picture Vocabulary Scale were completed during the first session, and the time reproduction task, phonological and visuo-spatial short-term memory tasks and free recall task were completed during the second session, which was carried out on a different day. All tasks apart from the phonological short-term memory task were conducted on a 14-inch LCD Acer laptop running Microsoft Windows XP. The time reproduction task was the same as used in Experiment 1. The free recall task was programmed in DMDX (Forster & Forster, 2003), and the visuo-spatial short-term memory task was programmed in VBA script within Microsoft PowerPoint. Responses to the free recall task and the phonological short-term memory task were verbal, and were recorded on a digital voice recorder for later analysis.

Results

For all analyses, the alpha level was set at .05 and statistical tests were carried out using SPSS 16.0 statistical software.

Time reproduction task

Proportional error scores were calculated as in Experiment 1. The error scores were subjected to a logarithmic transform prior to parametric analysis, to correct positive skew. However, this did not result in normally distributed data. A parametric analysis of variance (with Greenhouse-Geisser corrections) was employed to analyse the data, to enable comparison with the results of
Experiment 1. However, this was followed by a non-parametric analysis, as a more suitable method for skewed data.

The transformed error scores were analysed using a 2 (group: ASC vs. TD) by 7 (duration: 0.5s vs. 1s vs. 2s vs. 4s vs. 10s vs. 30s vs. 45s) mixed ANOVA with Greenhouse-Geisser corrections. There was no main effect of group, $F(1, 28) = 2.82$, $p < .11$, $\eta_p^2 = .10$, nor duration, $F(5.3, 148.9) = .83$, $p = .53$, $\eta_p^2 = .03$. There was, however, a Group × Duration interaction, $F(5.3, 148.9) = 2.53$, $p = .04$, $\eta_p^2 = .09$.

Error scores from each target duration then underwent non-parametric analysis using Mann-Whitney U tests. The ASC group had a significantly higher error score than the TD group for short target durations of 0.5 seconds, $M_{dn ASC} = 0.31$, $M_{dn TD} = 0.15$; $U = 61$, $p = .03$. They also had significantly higher error than the TD group for the longest target duration of 45 seconds, $M_{dn ASC} = 0.26$, $M_{dn TD} = 0.15$; $U = 51$, $p = .01$. The groups did not significantly differ in their performance on the intermediate target duration trials of 1, 2, 4, 10 and 30 seconds (all $p$-values > .05). Thus, the general pattern of higher error scores on the shortest and longest target durations in the group with ASC observed in Experiment 1 was replicated in Experiment 2. Group differences are illustrated in Figure 2.

Intra-individual variability of responses was then analysed. Variability scores were calculated as in Experiment 1 and the standard error of the means. Asterisks denote significant group difference at $p < .05$.

The transformed variability scores were analysed using a 2 (group: ASC vs. TD) by 7 (duration: 0.5s vs. 1s vs. 2s vs. 4s vs. 10s vs. 30s vs. 45s) mixed ANOVA. There was a main effect of duration, $F(6, 168) = 2.19$, $p = .04$, $\eta_p^2 = .08$, but no effect of group, $F(1, 28) = 1.25$, $p = .27$, $\eta_p^2 = .05$. Numerically, the ASC group produced more variable responses than the TD group, $M_{ASC} = 0.55$ ($SD = 0.57$), $M_{TD} = 0.34$ ($SD = 0.15$), but this did not reach significance. No interaction was present, $F(6, 168) = 0.51$, $p = .80$, $\eta_p^2 = .01$.

A correlational analysis was employed to investigate the role of intra-individual variability in overall error of reproduction. Spearman’s Correlation Coefficients were used throughout. In the ASC group, variability scores correlated with reproduction error only for the shortest duration of 0.5 seconds, $r = .67$, $p = .006$. In the TD group, variability did not significantly correlate with reproduction error at any target duration ($p$-values < .05). The general pattern of these correlations thus replicated those in Experiment 1.

Visuo-spatial short-term memory task

Participants were assigned a score out of 15 reflecting how many of the 15 trials they responded to correctly. There was no significant difference in performance between the two groups, $M_{ASC} = 12.3$ ($SD = 2.5$), $M_{TD} = 13.1$ ($SD = 1.6$); $t(28) = 1.12$, $p = .27$, $\eta_p^2 = .02$.

Phonological short-term memory task

Participants were assigned a score based on how many word lists they successfully repeated, in the order in which they were presented, without error. There was no significant difference in performance between the two groups, $M_{ASC} = 30.3$ ($SD = 9.0$), $M_{TD} = 36.1$ ($SD = 10.1$); $t(28) = 1.66$, $p = .11$, $\eta_p^2 = .08$.

Long-term memory free recall task

Two measures were calculated. Recall Score was equivalent to the number of words (out of a maximum of 15) successfully recalled after the filler task. A Reorganization Score was also calculated; this reflected how much the recalled material had been re-ordered by the participant in comparison to the order in which it had been presented. The score was calculated by taking the proportion of correctly recalled words that were produced non-consecutively. Reorganization away from serial order is thought to reflect more flexible encoding and retrieval strategies in episodic memory (see Savage, Deckersbach, Heckers, Wagner, Schacter, Alpert, Fischman & Rauch, 2001).

There was no significant difference between the groups in the number of words recalled, $M_{ASC} = 6.5$, $M_{TD} = 6.8$; $t(28) = 0.42$, $p = .68$, $\eta_p^2 = .01$. There was also no significant group difference in the probability of recalling words from the first three positions of the list, thought to reflect the primacy effect (e.g. Murdock, 1962), $M_{ASC} = .29$ ($SD = .14$), $M_{TD} = .33$ ($SD = .13$); $t(28) = 0.78$, $p = .44$, $\eta_p^2 = .02$. However, the ASC group had a significantly higher Reorganization Score than the TD group, $M_{ASC} = .84$ ($SD = .24$), $M_{TD} = .65$ ($SD = .22$); $t(28) = 2.19$, $p = .04$, $\eta_p^2 = .15$.

Figure 2  Chart showing mean error scores at each target duration for the Autism Spectrum Condition (ASC) group and the typically developing (TD) group. Error bars reflect the standard error of the means. Asterisks denote significant group difference at $p < .05$. 

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Correlational analysis

Correlations were assessed to investigate the role of both short-term and long-term episodic memory in time reproduction. Spearman’s Correlations were used throughout, due to the absence of a normal distribution of time reproduction error scores. A composite error score for durations thought to be subserved by short-term memory (short) was calculated by obtaining the mean error for 1, 2, 4 and 10 seconds. A composite error score for durations thought to rely on long-term episodic processes was calculated by taking the mean error at 30 and 45 seconds (long). This pre-planned analysis of composite scores was theoretically motivated; evidence from previous studies, as discussed in the introduction, has suggested that short durations of 1 to 10 seconds are processed by short-term memory mechanisms (Baudouin et al., 2006; Jueptner et al., 1995; Mangels et al., 1998; Mimura et al., 2000; Perbal, 2003; Pouthas & Perbal, 2004), and durations from 30 s onwards are thought to be subserved by episodic long-term memory (Mimura et al., 2000; Nichelli et al., 1993; Richards, 1973; Schmitter-Edgecombe & Rueda, 2008).

Error at the 0.5-second duration was not significantly correlated with any memory measure in either group (all p-values > .05). The short error score was significantly negatively correlated with the visuo-spatial short-term memory measure in both groups (rASC = −.52, p = .04; rTD = −.60, p = .02); more accurate reproduction of short temporal durations was associated with better visuo-spatial short-term memory abilities. No correlations with other memory measures were significant (all p-values > .05). The long error score was significantly negatively correlated with the Reorganization Score in the TD group (r = −.54, p = .04), where more accurate reproduction of long temporal durations was associated with more reorganization of items in episodic memory. This association was not found in the ASC group (r = .20, p = .94). No other correlations were significant (all p-values > .05).

Discussion

The current study consisted of two experiments, which clarified and extended the existing findings regarding temporal processing in ASC. First, they addressed the methodological concerns raised by previous studies. Time reproduction was measured when chronometric counting was prevented, and durations were filled by performing a simple concurrent task. A wide range of durations, from 0.5 seconds to 45 seconds, was tested. The first experiment found that individuals with ASC were impaired at reproducing both short durations of less than 2 seconds and longer durations of 45 seconds. The second experiment examined the proposal that the temporal reproduction difficulties observed in ASC are associated with key cognitive processes (Boucher, 2001) by relating temporal processing to memory abilities in children both with and without ASC.

The first experiment found that children with ASC were significantly impaired at reproducing short durations of 0.5 to 2 seconds, but were also significantly more variable in their responses than the TD group. Furthermore, variability of responding strongly correlated with error in the shorter but not longer durations. Given that intra-individual variability in temporal reproduction is thought to reflect attentional factors (Brown, 1997; Mullins et al., 2005; Pouthas & Perbal, 2004), these correlations suggest that attentional factors may have underpinned the impairment at these short durations. This finding, and the lack of impairment when reproducing durations of 4 to 30 seconds, suggests that subcortical timing mechanisms, sometimes known as the ‘internal clock’ (see Meck, 1983), are unimpaired in ASC. This agrees with the findings of both Mostofsky et al. (2000) and Martin et al. (2010) who found their perception of very short durations to be comparable to that of typical participants. The difficulties seen at these short durations in the current experiment appear instead to be mediated by explicit, cortical attentional processes, which compromise divided attention.

The ASC group were also found to be impaired at reproducing long durations of 45 seconds. Unlike performance at short durations, performance at 45 seconds did not appear to be related to attentional variability, and we speculated that reproduction at this duration was instead related to episodic memory abilities. The finding of an impairment at 45 seconds conflicts with Wallace and Happé’s (2008) finding of superior temporal reproduction of longer durations in ASC, suggesting that chronometric counting may have masked underlying impairment in the ASC group in their study. If our study provided greater ecological validity by preventing focused attention and counting, then the impairment we observed may reflect the difficulties children with ASC experience in meeting the timing demands of everyday life.

The second experiment investigated the relationship between performance in the time reproduction task and both short-term memory and long-term episodic memory abilities. The performance of the ASC group replicated the pattern of results seen in Experiment 1, demonstrating significantly poorer performance at the shortest duration of 0.5 seconds and longest duration of 45 seconds. Furthermore, the ASC group in the second experiment also had substantially higher error scores for both 1- and 2-second duration trials, although these differences failed to reach statistical significance. Variability was again strongly correlated with error in the reproduction of 0.5 seconds in the ASC group, providing further evidence for attentional variability rather than timing mechanisms as the mechanism underpinning the deficit seen at 0.5 seconds in ASC. As in Experiment 1, attentional variability did not appear to be able to explain the reproduction deficit seen at 45 seconds in the ASC group.
Analysis of the role of various memory processes in time reproduction revealed some interesting findings. In line with current theory (Baudouin et al., 2006; Jueptner et al., 1995; Mangels et al., 1998; Mimura et al., 2000; Perbal, 2003; Pouthas & Perbal, 2004), visuo-spatial short-term memory appeared to be associated with temporal perception at short durations of 1 to 10 seconds, in both groups. For durations shorter than 1 second, it is claimed that short-term memory does not play a part (Jueptner et al., 1995; Mangels et al., 1998); consistent with this claim, our results showed that no memory measure correlated with performance at 0.5 seconds in either group.

Durations above roughly 30 seconds are believed to be outside the realms of short-term memory, and it is thought that episodic memory may instead be involved (Mimura et al., 2000; Nichelli et al., 1993; Richards, 1973; Schmitter-Edgecombe & Rueda, 2008). We took both free recall scores and reorganization scores as measures of episodic memory. Interestingly, while the two groups did not differ on their absolute recall score, the group with ASC had higher reorganization scores. This is slightly surprising as Bowler, Gaigg and Gardiner (2008) found slightly reduced reorganization in ASC. However, in contrast to the current study, Bowler and colleagues utilized a multi-trial procedure with adult participants, which may account for the difference in results.

Our findings in the TD group supported the argument that processing durations above 30 seconds are related to episodic memory; performance at long durations of 30 and 45 seconds was correlated with the greater reorganization of episodic memories in a free recall task. We speculate that typically developing children use strategic, flexible organization of episodic memories and their associated temporal context to accurately represent durations beyond the capacity of short-term memory. This link between time perception of long durations and episodic memory agrees with existing research into time perception in amnesic patients (Mimura et al., 2000; Nichelli et al., 1993; Richards, 1973; Shaw & Aggleton, 1993). It is interesting, however, that the organization of episodic memories, and not simply retention of those memories, was associated with performance in typical children in this study. This raises the possibility that the active manipulation of memories aids us in making temporal judgements.

Conversely, there was no link between temporal performance at 45 seconds and any episodic memory measure in the ASC group, suggesting that the impairment at 45 seconds found in the ASC group is related to abnormal or under-use of typical episodic processes in timing. This was despite the finding that they actually engaged in more reorganization during the episodic memory task than the TD group. This suggests that although the participants in the ASC group were perfectly able to reorganize episodic memories, they did not spontaneously utilize this process when reproducing long temporal durations, and this resulted in poor performance.

We speculate that the difficulty in processing very short and long durations that we observed in the children with ASC has important functional significance. In everyday situations, events that require perception of short temporal durations may not be processed or responded to correctly by children with ASC when other stimuli capture their attention. This unreliable encoding of short-duration information, due to attentional variability, could hamper early sociocognitive development in children with ASC, for example by interfering in the sensitive timing demands of early face-to-face interactions and joint attention episodes.

With respect to long durations, given that previous findings suggest that memory for temporal context is impaired in ASC (Bennetto et al., 1996), it may be the case that the episodic memories the ASC group encoded during the target duration did not contain sufficient temporal information to be used to make explicit temporal judgements. This finding further illustrates the bidirectional developmental and functional links between episodic memory and temporal processing. The current study does not enable us to make judgements about the causal relationships between episodic memory and temporal processing. An underlying deficit in episodic memory in ASC could cause a corresponding deficit in temporal processing of long durations, but it is equally possible that a deficit in temporal processing of long durations may be the underlying cause of an impaired episodic memory system. However, given the relatively late emergence of episodic memory in the developing infant, we speculate that a temporal processing deficit may be developmentally primary. It is possible that an underlying impairment in the temporal processing of long durations interferes with the later development of the episodic memory system in infants with ASC, resulting in the encoding and retrieval of general memories which lack specific temporal information. This could ultimately result in bidirectionality; the resulting episodic memory deficit may then cause further impairment in temporal processing of long durations, where temporally impoverished episodic memories further impair the temporal system by preventing duration information from being obtained from items in memory. This could lead to difficulties in learning about the temporal features of common events, and problems with predicting their duration or occurrence. Such problems are often expressed through anxiety, behavioural difficulties, poor planning skills and an insistence on routine, all of which are common features of ASC (Hughes, Russell & Robbins, 1994; Ozonoff & McEvoy, 1994; Wing & Gould, 1979; Wing, 1996).

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