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BRIEF REPORT

Brief Report: Typical Auditory-Motor and Enhanced Visual-Motor Temporal Synchronization in Adults with Autism Spectrum Disorder

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Abstract
The perception of subsecond durations in adults with autism spectrum disorder (hereafter 'autism'; n = 25 Experiment 1, n = 21 Experiment 2) and matched typical adults (n = 24 Experiment 1, n = 22 Experiment 2) was examined by requiring participants to perform an action in time with auditory (Experiment 1) or visual (Experiment 2) events. Individuals with autism performed comparably to typical participants in the auditory task and exhibited less temporal error relative to their typical counterparts in the visual task. These findings suggest that perception of subsecond intervals is intact in autism, if not enhanced. Results support recent Bayesian theories of enhanced visual-perceptual precision in people with autism, and extend empirical support into the precision of subsecond temporal estimates.

Keywords Time perception · Sensorimotor coordination · Audition · Vision

Precise representation of temporal information is important for a host of social skills. For example, to understand the meaning of language one must accurately represent the duration of specific elements of the speech sounds and the silent intervals between them (Grossberg and Myers 2000; Repp et al. 1978), and measuring the temporal features of an interactant's movements enables us to make social judgments, such as the extent to which their smile is genuine (Krumhuber et al. 2007) or the mental or affective state they are communicating (Edey et al. 2017). Given the importance of temporal information for a host of social-cognitive skills, many of the social and communicative impairments exhibited by those with autism spectrum disorder (hereafter 'autism') have been proposed to stem from problems representing time (Falter and Noreika 2011; Wimpory et al. 2002). In line with this theory several studies have found temporal perception deficits in autistic individuals[1] (e.g., Allman et al. 2011; Brenner et al. 2015; Falter et al. 2012; Karaminis et al. 2016; Szelag et al. 2004). For instance, autistic adults (Martin et al. 2010) and children (Maister and Plaisted-Grant 2011) make larger temporal errors relative to typically developing individuals when reproducing the duration of a sensory event with a motor response.

On the other hand, autism has been characterized by strengths in a range of other perceptual abilities. For instance, individuals with autism are frequently found to exhibit superior performance on visual-spatial and pitch discrimination tasks (Ames and Fletcher-Watson 2010; Bonnel et al. 2003; Happé and Frith 2006; Keehn et al. 2017; see also Wallace and Happe 2008). Recent Bayesian models of autism have suggested that enhanced perceptual processing stems from highly precise sensory representations of current inputs at the expense of influences of context or top-down knowledge on those representations (e.g., Lawson et al. 2014; Palmer et al. 2017; Pellicano and Burr 2012; cf.; Remington and Fairnie 2017). Specifically, Bayesian models in typical individuals hypothesize that percepts emerge through the weighted combination of top-down expectations and sensory input, and that the weighting is determined by their

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[1] We use the term 'autistic individuals' as well as person-first language to respect the wishes of all individuals on the spectrum (see Sinclair 2013).

relative precision (Friston 2008). If individuals with autism have more precise representations of inputs this will therefore often result in more veridical perception. These models have been predominantly based upon research examining *what* is perceived in autism. However, the predictions also extend to temporal processing, such that autistic individuals would be expected to exhibit enhanced temporal processing in a range of settings, due to more precise sensory estimates or reduced influence of contextual biasing.

Notably, the existing time perception work in autism has focussed on perception of long durations (> 1 s; Allman et al. 2011; Brenner et al. 2015; Karaminis et al. 2016; Maister and Plaisted-Grant 2011; Martin et al. 2010; Szelag et al. 2004; Wallace and Happe 2008), and representation of long durations is assumed to depend upon a range of cognitive processes in addition to those directly representing time, including sustained attention, working memory and interoception (Ivry and Schlerf 2008; Mangels et al. 1998; Meissner and Wittmann 2011). It is possible, therefore, that timing impairments may arise as a consequence of impairments in these other processes.

The present study was designed to examine perception of subsecond intervals in adults with autism using a sensorimotor synchronization task adapted from Gowen and Miall (2005), and to compare synchronization with auditory (Experiment 1) and visual (Experiment 2) events. On each trial, participants were presented with a series of four sensory events at equal intervals of separation. Participants were required to listen to (Experiment 1) or observe (Experiment 2) the interval between events one and two, before depressing a button with their index finger in time with events three and four. We measured group differences in the temporal error between participants' actions and events three and four (absolute temporal difference between the motor and sensory events) to test whether there was evidence for impaired or enhanced performance in autism in either modality. If autistic individuals have difficulties with temporal perception—which contribute to their social and communicative problems—they would be hypothesized to show larger temporal errors than the typical group. Conversely, if atypically precise sensory representations extend to the temporal domain, autistic individuals would be expected to show smaller temporal errors than the typical group.

Experiment 1

Participants

Twenty-seven typical adults and 28 adults with autism were recruited from the local research volunteer database, and all reported normal hearing. One participant with autism was excluded because they gave insufficient responses (> 20% missed trials). Two participants with autism and three typical participants were excluded because their responses on the auditory task were 2.5 standard deviations above the group mean. These exclusions resulted in a final sample of 24 typical participants (mean age = 33.88 years old, SEM = 2.05 years, 23 males) and 25 participants with autism (mean age = 38.20 years, SEM = 2.82 years, 20 males).

An independent clinician diagnosed participants in the autism group according to DSM-IV criteria (American Psychiatric Association 1994), and the Autism Diagnostic Observation Schedule- 2 (ADOS-2, Lord et al. 2012) was administered to confirm participants' current level of social functioning. The two groups were matched on Full-Scale IQ (FSIQ), as measured by the WAIS for the autistic participants and WASI for the typical group ($t(47) = 1.07$, $p = .289$, $d = 0.31$), age ($t(47) = 1.23$, $p = .224$, $d = 0.46$) and sex (Fishers Exact Test, $p = .189$), but, as expected, there was a significant difference between the groups in Autistic Quotient (AQ; Baron-Cohen et al. 1995) scores ($t(47) = 6.81$, $p < .001$, $d = 1.95$; see Supplementary Table 1).

Procedure

The experiment consisted of an auditory-motor synchronization task. The stimulus was a 500 Hz tone presented for 100 ms at ~ 75 dB via speakers, located at 10 cm to the right and left of body midline. On each trial the tone stimulus was presented four times with a fixed silent interval between tones (300, 400, 500, 600, 700, 800, or 900 ms). The test interval presented in a given trial was determined randomly and 30 trials were presented. As part of the onscreen instructions, examples of the fastest (300 ms) and slowest (900 ms) test intervals were presented, and the participants completed two practice trials—one at the slowest and one at the fastest speed. Participants were instructed that on each trial four tones would be played, separated by a constant duration. Participants were instructed to assess the duration between the first and second events, and to tap the spacebar in time with the third and fourth. During the trial the screen was blank, and after the fourth tone a fixation cross appeared for 500 ms to signal the start of the next trial. If the participant failed to perform one or both of the required responses within a trial, the trial was omitted from analysis.

Results and Discussion

Response omissions were low (autism group mean = 0.36/30 trials, SEM = 0.13; typical group mean = 0/30 trials, SEM = 0), and hence not analyzed further. Greenhouse-Geisser corrections were applied where necessary, and all multiple comparisons are reported with Bonferroni corrections. Temporal error was defined as the mean absolute deviation between the time of the first and second response and the onset of the third and

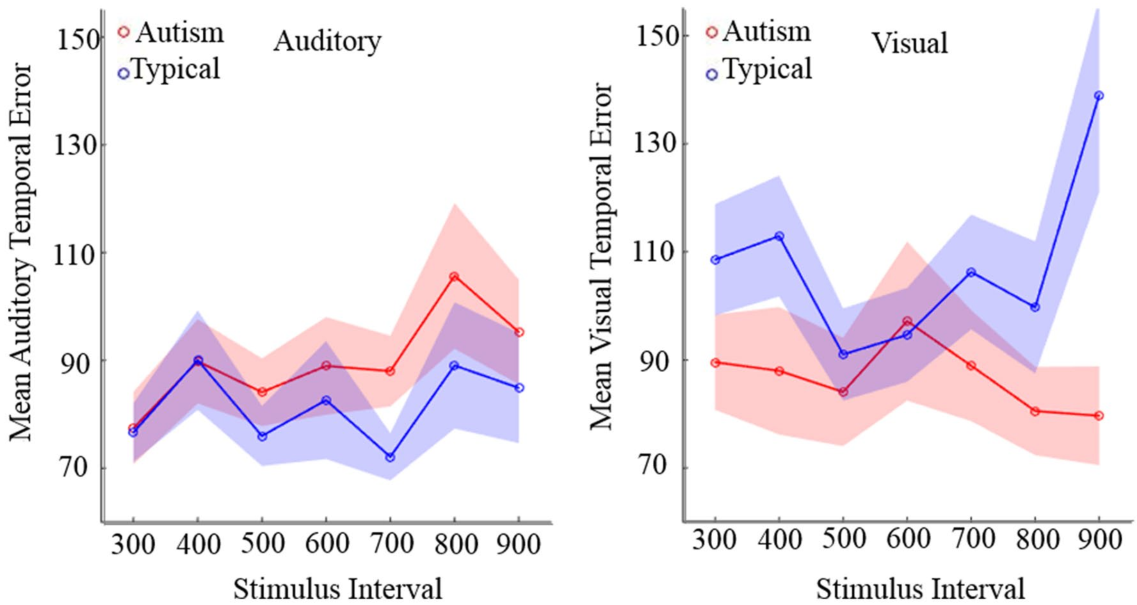

Fig. 1 Left: Mean auditory-motor error scores calculated as the absolute mean deviation error of both motor responses from the auditory stimulus in Experiment 1. Right: Mean visual-motor error scores calculated in the same way as in Experiment 1 but with visual, not auditory sensory events. Scores closer to zero represent more accurate performance. Shaded areas represent the SEM

fourth tone events, respectively (mean (|tone 3—response 1|, |tone 4—response 2|)). Scores closer to zero indicated more accurate performance. To examine group differences in auditory temporal error a 2 × 7 mixed ANOVA was performed on the temporal error scores, with group (autism or typical) as a between-participant factor and test duration (300–900 ms) as a within-participant factor. There was no main effect of group ($F(1,47) = 0.19$, $p = .663$, $\eta_p^2 = 0.004$) or interval duration ($F(4.50,211.34) = 1.17$, $p = .142$, $\eta_p^2 = 0.035$), and no interaction between group and duration ($F(4.50,211.34) = 1.61$, $p = .167$, $\eta_p^2 = 0.033$, see Fig. 1a).

As a post-hoc analysis we also examined whether there was evidence of a quadratic trend in errors across duration. If perception is influenced by the context, one might anticipate that there are greater errors at extreme durations due to biasing towards the mean interval ('central tendency effect'; Karaminis et al. 2016). However, there were no such patterns in the data—there was no quadratic effect across interval duration ($F(1,47) = 0.532$, $p = .980$, $\eta_p^2 < 0.001$), or quadratic interaction between group and duration ($F(1,47) = 0.194$, $p = .662$, $\eta_p^2 = 0.004$).

Experiment 2

Experiment 1 demonstrated intact—not impaired nor enhanced—auditory-motor synchronization in adults with autism at subsecond delays. However, it has previously been demonstrated in studies with typical participants that temporal resolution is higher in the auditory modality than in other sensory modalities such as vision (Grondin 1993; Grondin et al. 1998; Matthews and Meck 2014; Shi et al. 2013). Given that findings of enhanced perceptual precision in autism are hypothesized to reflect lesser impact of top-down representations on perceptual processing (Lawson et al. 2014; Pellicano and Burr 2012), and that top-down information is weighted more highly when sensory evidence is poor (Friston 2008), it is likely that a temporal advantage may be more apparent in autism in a visual rather than an auditory task. Experiment 2 therefore used the same paradigm as Experiment 1 but presented visual, rather than auditory events.

Participants

The same method of recruitment was used as in Experiment 1, which resulted in 25 typical adults and 26 adults with autism, all reporting normal or corrected-to-normal vision. Five participants with autism and four typical participants were excluded based on the same criteria used in Experiment 1 (see Supplementary Materials for additional information). These exclusions resulted in a final sample of 22 typical participants (mean age = 32.77 years, SEM = 1.95, 21 males) and 21 participants with autism (mean age = 35.43 years, SEM = 3.02 years, 18 males). As in Experiment 1, an independent clinician diagnosed participants in the autism group according to DSM-IV criteria, and the ADOS-2 was administered to confirm participants' current level of social functioning. The two groups were matched on FSIQ ($t(41)=1.50$, $p=.142$, $d=0.46$), age ($t(41)=0.75$, $p=.460$, $d=0.23$) and sex (Fishers Exact Test, $p=.345$), but, as expected, there was a significant difference between the groups in AQ scores ($t(41)=5.82$, $p<.001$, $d=1.78$; see Supplementary Table 2).

Procedure

The procedure was identical to that in Experiment 1 apart from the stimulus—a white dot (3° diameter visual angle when viewed at 40 cm) presented (for 100 ms) in the centre of a black computer screen (13 inches, 60 Hz, 98.46 DPI).

Results and Discussion

Response omissions were low (autism group mean = 0.38/30 trials, SEM = 0.18, typical group mean = .41/30 trials, SEM = 0.16) and hence not analyzed further. In contrast with Experiment 1, the analysis of temporal error revealed a main effect of group ($F(1,41)=4.24$, $p=.046$, $\eta_p^2=0.094$), driven by the autism group producing responses that were more accurate (M = 86.86 ms, SEM = 7.15) compared to the typical group (M = 107.45 ms, SEM = 6.99). There was no main effect of interval duration ($F(4.66,191.12)=1.15$, $p=.334$, $\eta_p^2=0.027$), and a trend for an interaction between group and duration ($F(4.66,191.12)=2.12$, $p=.069$, $\eta_p^2=0.049$).

As in Experiment 1, in a post-hoc analysis we analyzed the quadratic trends in the data to examine possible biasing of responding towards the mean duration. There was also no quadratic effect of duration across groups ($F(1,41)=2.61$, $p=.114$, $\eta_p^2=0.060$), but importantly there was a quadratic interaction between group and duration ($F(1,41)=6.68$, $p=.013$, $\eta_p^2=0.140$). This interaction was driven by the typical group showing a quadratic trend ($F(1,21)=6.46$, $p=.019$, $\eta_p^2=0.235$) across the test durations (i.e., poorer performance at the extreme test durations relative to the midpoints) but not the autism group ($F(1,20)=0.39$, $p=.385$, $\eta_p^2=0.038$; see Fig. 1b).

General Discussion

The present two experiments provide evidence that adults with autism exhibit comparable subsecond temporal precision to typical participants in an auditory synchronization task, but enhanced precision in a similar visual task. These findings therefore provide support for the hypothesis that individuals with autism exhibit enhanced visual-perceptual precision, consistent with the model of Pellicano and Burr (2012), and extend the findings into the precision of subsecond temporal estimates.

It is likely that the enhanced temporal precision in autism was only found in vision, not audition, due to lower temporal resolution in vision in typical individuals (Grondin 1993; Grondin et al. 1998; Matthews and Meck 2014; Shi et al. 2013). Specifically, Bayesian models in typical individuals hypothesize that sensory evidence is typically weighted by its precision (Friston 2008). Thus, in typical individuals, when the sensory evidence is less precise (i.e., during visual temporal perception) there is greater reliance on contextual information, or 'priors'. Consistent with this prediction, our posthoc analysis showed evidence of a central tendency effect—demonstrated through a quadratic trend across duration—in the visual, but not auditory, experiment in the typical group. We may therefore speculate that this difference between groups only emerges in situations where typical individuals exhibit lower temporal resolution, such as when perceiving subsecond visual events.

As noted, much of the previous literature on temporal processing in autism has found deficits, unlike the present study. The most notable methodological difference likely to account for the discrepancies is that most of the previous studies have tested durations greater than 1 s in contrast with the present study, and these judgments rely heavily on a range of cognitive processes in addition to basic timing mechanisms (Ivry and Schlerf 2008). Impairments may therefore arise due to atypicalities in these other processes. Of course, use of subsecond durations only minimizes rather than eliminates the reliance on these other processes, and therefore future work must also disentangle the contribution of other processes—e.g., those required for action control and working memory—even in these paradigms (see Falter et al. 2012). Furthermore, the majority of studies have compared autistic children or adolescents to their typical peers (e.g., Gil et al. 2012; Jones et al. 2009; Karaminis et al. 2016; Mostofsky et al. 2000), in contrast with the adults studied in the present experiments, and the atypical developmental trajectory in autism may generate differences in findings dependent upon participant age. Finally, as discussed, the differences that we observe between auditory and visual tasks suggest that autistic group enhancements will not be ubiquitous, and that the sensory modality and precision of sensory evidence may determine the nature of differences between groups (e.g., see Gowen and Miall 2005).

Our finding that temporal perception of subsecond durations is intact in autism, if not enhanced, provides less support for the hypothesis that impaired temporal resolution contributes to the social and communicative difficulties in autism (e.g., Wimpory et al. 2002). The finding of high temporal precision likely relates instead, however, to areas of superior functioning in autism, e.g., domains of exceptional talent (Happe and Frith 2006), and may also contribute to the negative experiences of sensory overload (Kirby et al. 2015). Furthermore, the findings suggest that areas of difficulty in autism could be scaffolded around this area of superior temporal functioning, e.g., motor control difficulties (Baranek 2002; Mosconi and Sweeney 2015) may be improved through interventions requiring individuals to attend to, and control, the temporal features of their actions.

In conclusion, the present findings provide evidence that autistic adults exhibit intact auditory-motor temporal synchronization, and enhanced visual-motor synchronization at subsecond durations. The current results extend the support for enhanced perceptual precision in autism to representation of temporal subsecond information.

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Author Contributions All authors contributed to the design of the study and were involved in writing the manuscript. RE and RB collected the data. RE analysed the data. CP supervised the work.

Compliance with Ethical Standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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