Abnormal Timing and Time Perception in Autism Spectrum Disorder? A Review of the Evidence

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1 Introduction

Autism spectrum disorders (ASD) is a cluster term for impairment in areas such as communication, social interaction, and imagination, and restricted and repetitive behaviors. Affected individuals, who grow up with this disorder, appear to perceive the world in profoundly different ways, and this may ultimately underlie the manifestation of diagnostic behavioral phenotypic characteristics (as for other forms of psychological disorder; e.g., schizophrenia, ADHD, other developmental disorders). The question as to whether some of these differences are attributable to pathophysiological differences in how the brain keeps time has recently become a focus of autism research. So too has the nature of the relationship between timing and time processing and other cognitive abilities that are compromised in ASD (e.g., perception of temporal structure and social reciprocity, such as to and fro- in social exchanges; see Chapter 3 of this book). As evidenced in this book, the interest in the potential correspondence of distortions in psychological time with diagnostic features of certain disorders is burgeoning in clinical populations often co-morbid to ASD including ADHD (Barkley et al., 1997; Noreika, Falter, and Rubia, 2013; Rubia et al., 1999; Toplack, Dockstader, and Tannock, 2006; Yang et al., 2007) and schizophrenia (Penney et al., 2005; see also Allman et al., 2014), however relatively little is known about timing abilities in individuals with ASD. This is despite the fact that it is widely acknowledged that these individuals have a poor sense of time at the intuitive level *“to a degree that is markedly discrepant with their level of intelligence”* (Wing, 1996: 89). There are at least three different ways in which time processing may be related to cognitive development, including a direct causal relationship or an associative interaction with other functional deficits (Falter and Noreika, 2011). The mechanisms by which a primary deficit of interval timing might contribute to diagnostic impairments

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have been speculated on in a temporal deficit hypothesis of autism (Allman, 2011; Allman and DeLeon, 2009). By this form of account, a fundamental building block of timing ability is required for cognitive development and psychophysiological differences in timing ability may account for diagnostic features of the disorder (see also Allman et al., 2012; Boucher, 2001).

The goal of this chapter is to outline the current literature on the state-of-the-field of autism timing research. The research on timing in ASD is like a jigsaw puzzle with many pieces missing, and there are clusters of findings related to islets of timing ability. Typically any findings of interest are confounded by other studies showing no effect. We begin by providing a general discussion of the relevance of timing and time processing to improving our understanding of ASD, which includes mention of certain studies (not included in Table 2.1). We then summarize research studies examining time processing in this population, which we have chosen to organize by duration range, and conclude by couching these findings in the “so what” for autism research.

2 Background

Autism is a spectrum developmental disorder, meaning that diagnosis of the condition falls along a *spectrum* of impairment/degree of severity. Thus, two children who are both diagnosed with ASD may present with behavioral symptoms that are quite different to the extent you might consider that they had different disorders; for example, one individual may be non-verbal; another may talk constantly about their fascination with trains, another may be an undergraduate or graduate student at a university. Of course, comparing the mental capabilities of such a broad range of individuals, who although they share the same diagnosis may nevertheless *appear* very different, is a challenge to psychological theories underlying this complex disorder. Individuals with ASD tend to present with differences in auditory and tactile perception. Sensory problems are based on how the brain processes incoming sensory input from multiple modalities across each of the five senses (vision, hearing, tactile, smell, and taste) that is likely intimately connected with the brain's sense of time, and ability to perceive the temporal structure of and between events.

It would be fair to say there are currently three dominant neuropsychological theories of ASD: First, the notion that there is under-connectivity between long-distance cortical regions and over-connectivity within regions (e.g., Frith, 2004). According to this way of thinking, affected individuals become overly concerned with local-level features at sometimes reduced processing of global-level events (i.e., weak central coherence; Happe and Frith, 2006). A second

TABLE 2.1 Details and results of the studies on timing studies in ASD and healthy controls.

Study	Paradigm	Modality	N (ASD/ Con)	Mean Age ASD/Con	% Males ADHD/ Con	Mean IQ ASD/ Con	% Diagnosis (% comorbidities)	Significant group differences ¹
Mostofsky et al., 2000	Unfilled interval discrimination thresholds (550ms)	aud	11/17	13.3/12.5	55/35	FIQ 101/105	100 Autism	n.s.
Szelag et al., 2004	Duration reproduction (1000–5500ms)	vis aud	7/7	12.6/n.r.	57/57	PIQ 82–102/95– 145	100 Autism	– Overestimation – > 3500ms – Underestimation – < 3500ms – CV – ADS – SD
Gowen and Miall, 2005	Synchronized button pressing with beeps (400–800ms) Continued button pressing after beeps (400–800ms)	aud	12/12	27.4/28.1	67/67	FIQ 104/112	100 AS	SD

¹ Only conditions and group comparisons yielding significant differences are reported in this column. If not further specified then all conditions yielded a significant group difference favouring Con.

Wallace and Happe, 2008	Duration estimation (2–45 s)	–	15/15 (LD)	14.3/14.7	80/87	RPM 26/24 BPVS 83/90	n.r. Autism or AS	–Diachronic thinking tendency – Temporal transformation – Temporal synthesis
	Duration reproduction (2–45 s)		25/25	14.1/13.8	100/92	FIQ 96/100	n.r. Autism or AS	n.s.
	Duration production (2–45 s)							ACC ²
Jones et al., 2009	Duration discrimination thresholds (640ms)	aud	72/26 22 SEN	15.6/15.6	92/96	FIQ 88/89 PIQ 93/93 VIQ 84/87	54 Autism; 4 Atypical Autism; 39 other PDD; 3 PDD unspecified	n.s.
Foss-Feig et al., 2010	Flash-beep illusion	aud-vis	29/17	12.6/12.1	59/82	FIQ 108/107 PIQ 110/103 VIQ 105/109	n.r. Autism, ASD	Higher probability of illusion within wider range of SOAs

² Superior performance in the ASD group.

TABLE 2.1 *Details and results of the studies on timing studies in asd and healthy controls (cont.)*

Study	Paradigm	Modality	N (ASD/ Con)	Mean Age ASD/Con	% Males ADHD/ Con	Mean IQ ASD/ Con	% Diagnosis (% comorbidities)	Significant group differences ¹
Martin et al., 2010	Duration reproduction (0.5–4.1 s)	aud	20/20	36/35	75/65	FIQ 106/108 PIQ 105/106 VIQ 107/108	100 ASD	– ADS – Overestimation > 2300ms – Underestimation < 2300ms – CV
Allman et al., 2011	Temporal bisection task (1/4 s; 2/8 s)	vis	13/12	10.3/10.3	100/75	VIQ 100/n.r.	100 Autism	– ACC (1/4 s) – shorter BP – WR (2/8 s)
Kwakye et al., 2011	Temporal order judgment (0–500ms)	vis aud aud-vis	35/27	12.2/11.7	86/81	FIQ 103/110	n.r. Autism, AS, PDD unspecified	Temporal order thresholds (aud, aud-vis)
Maister and Plaisted, 2011	Duration reproduction (0.5–45 s)	vis	21/21	11.3/10.7	95/62	RPM 40/38 BPVS 102/111	100 Autism	– PDS (0.5, 1, 2, 45 s) – Intraindividual variability PDS (0.5, 45 s)

Falter et al., 2012a	Simultaneity Judgments (0–100ms)	vis	16/16	24.7/26.7	94/88	FIQ 114/112 PIQ 114/114 VIQ 111/108	25 Autism; 75 AS	Simultaneity thresholds ²
Falter et al., 2012b	Temporal Generalisation (300–1500ms)	vis aud aud-vis vis-aud	18/19	25.3/26.1	94/79	FIQ 112/113 PIQ 112/114 VIQ 110/110	22 Autism; 78 AS	– <i>d</i> 'scores (ASD less sensitivity) – <i>c</i> scores (ASD more conservative responding)

Abbreviations: ACC = accuracy; ADS = absolute discrepancy scores; AS = Asperger Syndrome; aud = auditory; BP = Bisection Point; BPVS = British Picture Vocabulary Scale; Con = Control (neurotypical if not otherwise specified); CV = Coefficient of variation; DD = (individuals with) developmental disabilities; FA = functional age; FIQ = Full Scale Intelligence Quotient; LD = Learning Disability; MMN = Mismatch Negativity (i.e. an event-related potential associated with deviant stimulus processing in series of standard stimuli); MRT = mean reaction time; n.r. = not reported; n.s. = not significant; PDD = Pervasive Developmental Disorder; PDS = Proportional discrepancy scores (i.e. ADS/target duration); PIQ = Performance Intelligence Quotient; RPM = Raven's Standard Progressive Matrices; SD = standard deviation; SEN = special educational needs; SOA = Stimulus Onset Asynchrony; std. = standard; vis = visual; VIQ = Verbal Intelligence Quotient; WR = Weber Ratio (i.e. an index of sensitivity to durations).

focus is on pathophysiological differences in executive function (e.g., working memory, attention; see Russell, 1997) – these are abilities that are often related to some abstraction of time (event prediction, planning for events outside the present moment); and a third theory ascribing individuals with ASD reduced theory of mind skills (i.e., the ability to attribute mental states in order to understand behavior; see Baron-Cohen, Leslie, and Frith, 1985). It is beyond the scope of this chapter to discuss the different theories of ASD more fully, but see Belmonte et al. (2004).

Speculatively, a fourth neuropsychological theory of ASD could be formulated on the basis of anecdotal, clinical and behavioral observations of impairments in the *development* of timing and time perception in ASD (Allman, 2011; Boucher, 2001), although arguably, this is premature given the state of the field at this time. This is an attempt at relating autistic symptomology to posited timing differences, although the extent to which timing differences are found in other populations (i.e., ADHD) that present with very different symptoms is of interest (Falter and Noreika, 2011), and often speculations about which aspects of time processing are affected in ASD are untested. Boucher (2001) considered, “try to imagine periods of time longer than the lifetime of the universe...in fact, one cannot imagine a period of time longer than the lifetime of the universe except by thinking of a temporal succession of universes with cumulative lifetimes” (2001: 121). She suggests that there may be a close correspondence between the length (and complexity) of repeating behavioral units (e.g., stereotypies, rituals) and the ability to imagine extended time frames in ASD (mental concepts of time). As shorter and less complex stereotypies are usually observed with lower-functioning autistic individuals, and more complex, rigid routines are observed in those who are higher functioning. They may not be apparent at all in adults with high-functioning autism or Asperger syndrome (AS): it follows that a graded form of temporal insensitivity to duration might account for quantitative and qualitative differences in repetitive behaviors across the autistic spectrum (Boucher, 2001). A chapter by Allman and DeLeon (2009) extends this approach into formal models of interval timing, and provides a conceptual framework based upon indirect evidence linking posited differences in timing to diagnostic features of the disorder. For instance, repetitive, rhythmical behaviors may function to act as a form of behavioral clock, particularly if typical cognitive internal clock models are deficient (see Allman et al., 2014). “Stereotypies are typically produced in repeating cycles, and may be separated by (often short) intervals in time – continually measuring intervals in a repeating cycle requires less attentional resources (Lewis and Miall, 2003), and so repetitive motor behaviors may be a particularly effective time-parsing strategy for autistic individuals, and might

function to concretize and reduce the stressor of an imposed disorientation in time. Peeters and Gillberg (1999: 87) report that “most people with autism feel lost in a sea of time...they will often try to develop routines and rituals by way of compensation. They want all activities to be undertaken in the same sequence every day...and if the sequence of activities changes on a certain day, then they have behavior problems” [which can include rhythmic lower-order motor behaviors, e.g., head-banging, self-injury]. To reiterate the main point here, an autistic impairment in the perception of duration may be compensated for by the production of repetitive motor behaviors, and an overreliance upon intact abilities, such as sequencing and order, and the stringing together of temporal units of perseveration or habits” (Allman and DeLeon, 2009: 70–1).

What these commentaries are attempting to do is associate various aspects of the autistic phenotype, in terms of deficits in language and communication, social interaction and structured imaginative play and behavior, to posited deficits in some underlying mechanism of ‘keeping time’. But the nature of the interaction of timing and time processing to ASD and other developmental disabilities is unknown. “[Collectively] reports demonstrate complex associations between abnormally developing cognitive functions, and suggest that interval timing might play an important yet under-investigated role in developmental disorders by interacting with and modulating primary symptoms” (Falter and Noreika, 2011). Timing and time perception deficits likely play in a much larger symphony with other aspects of executive and cognitive functions in shaping the developing brain. The extent or “clout” that timing and time processing deficits play in characterizing not only the ASD phenotype but also other developmental and childhood disorders is currently uncertain.

There is neurophysiological evidence that the autistic brain has different absolute temporal windows for sensory integration and ‘temporal binding’ (Falter, Elliott, and Bailey, 2012; Falter et al., 2013; Foss-Feig et al., 2010; Rippon et al., 2007); and there are reports of abnormalities in the pre-attentive mismatch negativity (MMN) event-related potential to changes in duration (but not pitch) in speech sounds in individuals with ASD (Lepistö et al., 2005, 2006).

An MEG study reports enhanced temporal resolution for visual stimuli and reveals superior temporal event structure coding in individuals with ASD (Falter et al., 2013). These findings relate to short temporal intervals of ~57ms which are posited to correspond to units of subjective time (Brecher, 1932). An unpublished fMRI of supra-second duration visual ordinality comparison (by the first author) reveals that while unaffected children recruit cortico-cerebellar systems for timing relatively short durations (~2 s) and cortico-striatal systems for timing longer (~8 s) durations, children with ASD recruit cortico-striatal systems when timing short durations (but not long; the opposite

pattern). A possible explanation for the pattern of neural activity observed is that children with ASD may overly recruit a “beat-based” system when timing a stimulus. This may have relevance to explanations of ASD which posit a behavioral clock time parsing mechanism in which repetitive and highly predictable events occur that help to ameliorate anecdotal and clinical reports of being “lost in a sea of time” (Allman and DeLeon, 2009; Boucher, 2001), and clinical evidence that external rhythmical/timing cues can improve the quality of social interactions in children with ASD (see Chapter 3 of this book).

For instance, Trevarthen and Daniel (2005) examined video recordings of monozygotic twin 11 month old infants, one of whom later went on to receive a diagnosis of ASD. They report differences in the affected sibling in respect to the ability for prospective awareness – being able to anticipate and expect future social and non-social events – the temporal patterning and form of parent-infant interactions differed between the twins, which the authors postulated to be due to “prospective control of movements and anticipations in awareness,” related to changes in attention, motor tonus, emotion and initiative (2005: S25). Moreover, the discrimination of temporal synchrony between intermodal events (i.e., the sight and sound of the parent’s speech) during parent/infant interactions “may be the first step in developing a capacity to discriminate more complex and specific forms of language” (Bebko et al., 2006: 96). These authors report that autistic children (aged 4–6 years) reveal atypical responding to multimodal temporal asynchrony with language-specific stimuli.

Higher visual temporal resolution in a perceptual simultaneity task was related to increased developmental communication difficulties in ASD (Falter, Elliott, and Bailey, 2012). At the same time, diagnostic communication scores were correlated with a more conservative response bias in a cross-modal interval timing task (Falter, Noreika, Wearden, and Bailey, 2013).

Additional indirect evidence for a timing mediated deficit on secondary symptoms is provided by Hill (2004) who examined aspects of executive function: planning, flexibility, and inhibition. Moreover, sleep difficulties and differences in circadian function and clock genes have also been noted in ASD (Richdale and Schreck, 2009; Nicholas et al., 2007; Wimpory, Nicholas, and Nash, 2002).

3 A Review of the Evidence

The nature of empirical studies of time processing in ASD is summarized in Table 2.1. These include studies examining millisecond and suprasecond timing, perceptual and performance tasks, using a variety of neurophysiological and psychological methods in a broad range of samples of individuals with

ASD. This chapter could have been presented in several different ways based upon the complex arrangement of this variation, and we have chosen to subdivide the review by duration range. Of course, within each duration range there are a variety of studies recruiting different durations and methods, and nature of autistic sample. We will summarize each study individually before presenting our own summary of the weight of the evidence and asking “so what?”

3.1 *Millisecond Range*

Mostofsky et al. (2000) examined procedural learning and duration discrimination in children (mean age 13 years) with high-functioning autism ($IQ > 85$). Their perceptual duration discrimination task involved the presentation of pairs of identical tones, 50ms in duration. At the beginning of a trial, the two tones were separated by 550ms; following this, a second pair of identical tones (50ms in duration) were separated by a variable interval, either shorter or longer than 550ms. Participants were required to make ‘shorter’ or ‘longer’ judgments on these empty intervals, which were entered into a computer by the experimenter. These authors report no significant difference between affected and non-affected individuals when discriminating between empty millisecond intervals, although the scores for those with ASD did tend to be higher (indicating poorer discrimination) for durations and lower (indicating better discrimination) for a pitch discrimination control task. This is in line with known sensory differences in ASD.

Another auditory perceptual task (Jones et al., 2009) used filled millisecond durations (tones) and found no group differences between duration (nor pitch or intensity) discrimination between adolescents with ASD (childhood autism and pervasive developmental disorder not otherwise specified) and non-affected controls. However, they did observe small subsets of the ASD sample that showed superior pitch discrimination, and inferior duration discrimination.

Gowen and Miall (2005) administered a battery of tasks designed to tap cerebellar function in adults with AS. Their timing tasks involved finger tapping, in a synchronization and continuation arrangement. The task included four identical tones, separated by identical intervals (that ranged from 400–800ms). The synchronization phase required button presses ‘in time’ with the third and forth tones, and in the continuation phase, the third and forth tones were omitted (button presses indicating the timing of the third and forth tones were still required). In the synchronization phase, they report that individuals with AS revealed greater absolute error, more variability and responded earlier than non-affected controls to the forth tone. In the continuation task, those with AS revealed the same pattern as in the synchronization task. The authors suggest that this may reflect “a fixed and nonadjustable mechanism of timing control”

in affected individuals, and posit the collection of findings to differences in the integration of sensory signals with motor output in AS.

Foss-Feig et al. (2010) employed the flash-beep illusion, in which the presentation of a single light flash with multiple sounds results in the erroneous perception of multiple flashes. The breadth of the temporal window by which these multisensory stimuli are bound and produce the illusion was reported to be longer in those affected with ASD. In a related study, Kwakye et al. (2011) examined unisensory and multisensory temporal function on a temporal order judgment task by requiring children with ASD (8–17 years) to indicate which of two stimuli was presented first. Although there were no differences with respect to the visual modality, thresholds were higher for auditory stimuli, and multisensory processing was superior in children with ASD (see also Russo et al., 2012). However, in a separate study using visual stimuli in a perceptual simultaneity design, individuals with ASD judged two stimuli to be asynchronous at a smaller temporal difference between their onsets than non-affected controls, suggesting superior visual temporal resolution in ASD (Falter, Elliott, and Bailey, 2012). “Thus, increased temporal resolution might be a signature of the autistic cognitive profile differentiating it from other developmental and psychiatric disorders” (2012: 4). MEG signatures pointed towards enhanced access to early visual brain processes in ASD underlying superior visual temporal resolution (Falter et al., 2013). Speculatively, individuals with ASD might be parsing temporal events more than non-affected controls extending previous findings of increased spatial detail-focused perception, as proposed by Weak Central Coherence theory (Happé and Frith, 2006), to the temporal domain.

Hence, superior performance in aspects of time processing that are based on ‘weak temporal coherence’ seems to exist alongside impaired performance in other timing aspects, such as interval timing. Indeed, Falter et al. (2012) conducted a psychophysical study using a repeated standards version of a temporal generalization task with visual, auditory, and multimodal stimuli and found lower sensitivity to duration, particularly when the standard was an auditory stimulus. They employed two standard durations (600 and 1000ms) and found the scalar property to be preserved despite of impaired sensitivity to temporal intervals.

3.2 *Multisecond Range*

Szelag et al. (2004) reported that children with high-functioning autism (9–16 years) are severely impaired in their ability to reproduce both auditory and visual target durations (between 1–5 s). In this arrangement, a target stimulus duration was presented and after a 2 s interstimulus interval the stimulus would be presented again. Participants were required to press a button at the

time of the judged target duration. Individuals with ASD tended to reproduce all durations as 3.0–3.5 s. A related study was conducted by Martin, Poirier, and Bowler (2010). They report an autistic tendency to make less accurate and more variable reproductions, and enhanced underestimation of durations over ~2.3 s. In a separate study, temporal reproduction of visual durations of 0.5–45 s was examined by Maister and Plaisted (2011) who employed an additional concurrent verbal task in an attempt to reduce the possibility of chronometric counting. These authors report difficulties by individuals with ASD with accurate reproductions of durations under 2 s and the longest duration (45 s), but not with durations around 4–30 s, in addition to increased overall variability in comparison to non-affected controls. The authors attributed the pattern of their findings to differences in attention (for short durations) and episodic memory processing (for the longest ones).

A temporal bisection perception procedure employing visual stimuli (Allman, DeLeon, and Wearden, 2011) reveals differences in time perception in children (aged 7–16 years) with ASD across two different duration ranges (1 to 4 s and 2 to 8 s). In the ASD sample, lower subjective points of equality were somewhat predictive of working memory and diagnostic language and communication impairment, and reduced temporal sensitivity for the longer set of durations was found. Parents of affected children also tended to rate their child's "sense of time" as poor. The scalar property was observed, although superimposition was generally not as well obtained for affected individuals. However in a separate bisection study (Gil et al., 2012) employing four pairs of duration ranges (two short: 0.5–1 s, 1.25–2.5 s; and two long: 3.12–6.25 s, 7.81–16.62 s) and auditory stimuli, no evidence of timing impairment in children of a similar age range (the majority of whom had AS) was found.

Wallace and Happe (2008) extended the range of durations tested with an ASD sample to 2–45 s on three different types of timing tasks: duration estimation (verbal numerical judgment), reproduction, and production, in which verbal "start" and "stop" cues were used to mimic more naturalistic arrangements. They report unimpaired time estimation and production, and more accurate reproduction (even to the longest duration of 45 s), with the possibility of increased task difficulty on shorter time intervals during reproduction.

3.3 *Mental Concepts of Time*

Boucher et al. (2007) report that children with ASD (7–16 years) are unable to i) think about past or future stages of current situation, ii) understand that things can change or evolve over time but are still the same thing, and iii) that successive events are part of a unitary process (see also Montangero, 1992). Zukauskas, Silton, and Assumpção et al. (2009) assessed temporality experience in

individuals with AS qualitatively and found that past experiences dominated their sense of time while a “restricted mode of existence” (p. 104) was expressed with respect to present and future dimensions.

4 Summary

Surveying the spread of the extant findings just presented, it is clear there may be abnormal time processing in ASD – but evidence is relatively sparse, and there is much scientific diversity in the findings, including somewhat inconsistent empirical evidence that individuals with ASD display characteristic differences in aspects of time processing function. However a striking universal consistency amongst studies presented in this chapter is a tendency to observe increased variability in autistic time processing.

Here we present our main observations of the state-of-the findings as they relate to topics discussed in this chapter. These very general summary statements are not intended as definitive statements of timing ability in ASD, more a mere recapitulation of the ‘general ballpark’ of observed trends.

First, studies in the sub-second range have tended to find superior temporal discrimination differences in individuals with ASD. This may correspond to units of subjective time and sensory processing differences in ASD (Leekam et al., 2007).

Second, studies in the supra-second range have tended to find impairments in longer durations outside the bounds of the ‘psychological present’ (James, 1890), coupled with increased variability.

Third, there is initial evidence for problems with conceptual notions of time in ASD. These include empirical, clinical, and anecdotal reports of lack of a “time sense” (Boucher, 2001; Wing, 1996) to thinking forwards and backwards in time (Boucher, 2007).

The very fact that somewhat similar effects have been reported with a broad range of affected individuals suggests some fundamental significance or underlying tendency towards altered time processing. For instance, superior temporal visual acuity may be adaptive if other forms of time processing are impaired, or if other senses are differentially functional, as has been suggested in ASD. On the other hand, the apparent inconsistency between related studies that would otherwise be expected to provide a consistent pattern of results (e.g., Allman et al., 2011; Gil et al., 2012) is a challenge for the view that a core disability in ASD is to be found in time processing. Nevertheless, the study of time processing in ASD resembles that of other aspects of the autistic cognitive profile, such as visuo-spatial skills, which are also characterized by inconsistencies

in findings (see recent meta-analysis by Muth, Hönekopp, and Falter, *in press*), but which are without doubt being considered a domain of altered processing in ASD.

5 The “So-what” for Autism Research

This chapter has outlined the findings from a diverse range of studies examining different aspects of time processing in ASD, in the hope that an understanding of the temporal scaffolding of the autistic mind might be elucidated. Given the discrepancy in stimulus duration, modality, and IQ between studies it is difficult to discern any clear picture at this time of the ‘state’ of autistic time processing. This will require considerably more research being done in this area, using a range of tasks and time scales in the same diagnostic samples, in addition to other developmental disorders.

It is not beyond the bounds of feasibility to see how a deficit in time processing might be relevant to the three dominant accounts of ASD (outlined earlier), and other new theories of ASD incorporate posited abnormalities in time processing in ASD (e.g., see Gepner and Feron, 2009; Welsh, Ahn, and Placantonakis, 2005). However, it is important to remember that the relationship between interval timing and higher mental representations of time is currently unspecified, and so any conceptualizations about time in the autistic mind should be made with caution. The association of interval timing abnormalities and other functional deficits is likely. “For instance, although a Theory of Mind deficit can hamper the understanding of social situations in its own right, an additional interval timing deficit could result in a lack of precise perception of temporal cues of eye gaze, and thereby increase misinterpretations of social situations. It has been proposed that different symptoms can be independent dimensions of impairment, which nevertheless interact with and modulate one another, leading to the characteristic phenomenology of an individual with a developmental disorder (Happe et al., 2006). In this line of thought, interval timing abnormalities might interact with primary dysfunctions” (Falter and Noreika, 2011: 1). It remains untested whether repetitive behaviors of the type outlined by Boucher (2001) and Allman (2011) are related to pathophysiological differences in timing and time perception. There is nevertheless much collective support for the notion that fundamental differences in time processing underlie aspects of the disorder (see also Allman and Meck, 2012).

Collectively the growing body of recent empirical findings reviewed in this chapter suggests there are quantifiable differences in functions of time processing in affected individuals, but this varies by duration range, possibly

becoming superior for the millisecond range, probably tapping perception, and getting worse as duration increases into the bounds of secondary executive functions (working and episodic memory, sustained attention).

The extent of the influence of time processing differences to the manifestation of autistic qualities is unknown – although there may be links with communication (Allman et al., 2011; Falter, Elliott, and Bailey, 2012; Falter et al., 2013) – and is possibly mediated by its association with other cognitive abilities. For example, there are additional studies which we did not include into Table 2.1 but which are nonetheless worth mentioning: Zukauskas et al. (2009; AS only, no controls) using a semi-structured interview found individuals affected with ASD to have an abnormal perspective of themselves through time. Oram et al. (2005) studied rapid auditory processing – tasks that have been used to establish the ‘temporal processing deficit’ in dyslexia (which is somewhat different in nature than the timing mechanisms which are the focus of this chapter). Oram Cardy et al. suggested that impaired rapid temporal processing might rather be associated with language impairment than with ASD *per se*.

The extent to which any temporal deficit in ASD is fundamental to the disorder, and to other related disorders (ADHD, schizophrenia), and the role this may play in the ontology of the phenotype is clearly uncertain (Falter and Noreika, 2011). However, this is a fascinating and potentially fruitful question that would be informative to child development at a general level. The ultimate aim for future studies of ASD and time processing is to “fill the gaps” and try to sew the pieces together, and to examine the relevance of observed differences to clinical features of the disorder, and to temporal supports in their remediation. Additional studies in other childhood disorders are necessary to discern the selectivity of timing differences in autism and other developmental disabilities (see Falter and Noreika, 2011).

Perhaps the best lens by which to view time processing deficits in ASD is one that has more precise acuity (than is typical) with millisecond durations and increased variability (or blurriness) with longer durations, and with a ‘big picture’ view encompassing social and developmental aspects of timing; such as the apparent importance of timing to the development and maintenance of social interactions, and the perspective that different aspects of timing (sub-second, multi-second, and concepts of time) are component parts of a fundamental timing mechanism. Coupled with this is the view that interval timing is integral to other aspects of cognitive function (Lustig et al., 2005; Lustig and Meck, 2011).

As has been introduced in this chapter, there is an emerging conceptual “frame of reference” for understanding how a deficit in time processing might impact the autistic mind: speech and language difficulties; the importance of temporal information in social interactions; and the potential for a limited cognitive sense of time to influence higher-order cognitive functions

(e.g., executive functions) and sensory perception. This is an exciting time for autism research in particular, and the study of time processing differences in other related populations in general.

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