



## Is there a generalized timing impairment in Autism Spectrum Disorders across time scales and paradigms?



Sofia Isaksson<sup>a,1</sup>, Susanna Salomäki<sup>a,1</sup>, Jarno Tuominen<sup>a,b</sup>, Valtteri Arstila<sup>c,d</sup>,  
Christine M. Falter-Wagner<sup>e,f,g,2</sup>, Valdas Noreika<sup>h,a,\*,2</sup>

<sup>a</sup> Department of Psychology and Speech-Language Pathology, University of Turku, Turku, Finland

<sup>b</sup> Turku Brain and Mind Center, University of Turku, Turku, Finland

<sup>c</sup> Department of Philosophy, University of Turku, Turku, Finland

<sup>d</sup> Turku Institute for Advanced Studies, University of Turku, Turku, Finland

<sup>e</sup> Department of Psychiatry, Medical Faculty, LMU Munich, Munich, Germany

<sup>f</sup> Institute of Medical Psychology, Medical Faculty, LMU Munich, Munich, Germany

<sup>g</sup> Department of Psychology, University of Cologne, Cologne, Germany

<sup>h</sup> Department of Psychology, University of Cambridge, Cambridge, UK

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### ABSTRACT

Individuals with ASD have abnormal motor and perceptual functions that do not currently form diagnostic criteria of ASD, but nevertheless may affect everyday behaviour. Temporal processing seems to be one of such non-diagnostic yet impaired domains, although the lack of systematic studies testing different aspects of timing in the same sample of participants prevents a conclusive assessment of whether there is a generalized temporal deficit in ASD associated with diagnostic symptoms. 17 children diagnosed with ASD and 18 typically developing age- and IQ-matched controls carried out a set of motor and perceptual timing tasks: free tapping, simultaneity judgment, auditory duration discrimination, and verbal duration estimation. Parents of participants filled in a questionnaire assessing the sense and management of time. Children with ASD showed faster and more variable free tapping than controls. Auditory duration discrimination thresholds were higher in the ASD group than controls in a sub-second version of the task, while there were no group differences in a supra-second discrimination of intervals. Children with ASD showed more variable thresholds of simultaneity judgment, and they received lower parental scores for their sense and management of time. No group differences were observed in the verbal duration estimation task in the minute-range. Different timing functions were correlated in the ASD group but not among controls, whilst several timing measures correlated with ASD symptoms. We conclude that children with ASD show a broad range of abnormalities in temporal processing tasks including motor timing, perceptual timing, and temporal perspective.

### 1. Introduction

Autism Spectrum Disorder (ASD) is marked by persistent and severe deficits in social communication and interaction, and repetitive patterns of action, behaviour or interests. Primary symptoms present from early childhood and affect everyday functioning (American Psychiatric Association, 2013). Furthermore, both clinical reports and research literature suggest that the primary diagnostic characteristics of ASD are commonly accompanied by secondary difficulties, such as atypical motor (Ming et al., 2007) and sensory (Blake et al., 2003; Milne et al., 2002) processing. Among such secondary characteristics, difficulties in

timing might be a key part of the autistic cognitive profile (e.g., Allman et al., 2011; Bebko et al., 2006; Boucher et al., 2007; Brodeur et al., 2014; Falter et al., 2012a, 2012b, 2013; Gepner and Féron, 2009; Gowen and Miall, 2005; Karaminis et al., 2016; Kargas et al., 2015; Kwakye et al., 2011; Maister and Plaisted-Grant, 2011; Martin et al., 2010; Szelag et al., 2004; Whiting and Dixon, 2015; Ribeiro Zukauskas et al., 2009; for review and clinical discussion, see Allman and Falter, 2015; Boucher, 2001; Falter and Noreika, 2014; Stevenson et al., 2016; Welsh et al., 2005). However, timing deficits in ASD are not unequivocal (e.g., Bebko et al., 2006; Gil et al., 2012; Glazebrook et al., 2008; Jones et al., 2009, 2017; Kwakye et al., 2011; Mostofsky et al., 2000;

\* Corresponding author. Department of Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK.

E-mail addresses: [vn261@cam.ac.uk](mailto:vn261@cam.ac.uk), [valnoreika@gmail.com](mailto:valnoreika@gmail.com) (V. Noreika).

<sup>1</sup> S.I. and S.S. contributed equally to this work.

<sup>2</sup> C.M.F. and V.N. share the last-authorship.

Wallace and Happé, 2008).

Temporal processing functions can be divided into motor timing, perceptual timing and temporal perspective. Neurocognitive processing of these timing functions involves both shared and function-specific neural mechanisms (Frost and McNaughton, 2017; Merchant et al., 2013; Muller and Nobre, 2014; Schubotz et al., 2000). Motor timing refers to the temporal resolution of motor behaviour, which is typically tested using free or synchronized motor tapping tasks. Even though motor timing has not been widely studied in ASD, a preliminary study of synchronized tapping found that individuals with Asperger syndrome in comparison to typically developing controls responded earlier and more variably to the pacing stimuli (Gowen and Miall, 2005), indicating that ASD may be associated with impaired motor timing. Arguably, abnormal timing patterns could contribute to other motor impairments in ASD (Ming et al., 2007; Sacrey et al., 2014), although replication studies of tapping tasks are needed before drawing any firm conclusions.

While motor timing does not require explicit judgment of duration or temporal succession of stimuli, perceptual timing refers to perceptual evaluation of temporal processing, which can be further subdivided into event timing, interval timing and retrospective tasks. Event timing (also termed temporal event-structure coding) comprises the perception and judgment of the relative timing of events, which can be assessed for instance by measuring judgments of simultaneity and temporal order. In two previous studies of visual simultaneity judgments we have found abnormal temporal event-structure coding in ASD (Falter et al., 2012a, 2013). In particular, adults with high-functioning autism and Asperger syndrome had lower simultaneity thresholds (Falter et al., 2012a) and were more able to discriminate between real and apparent simultaneity (Falter et al., 2013) than typically developing controls, pointing to increased resolution of the timing of events in ASD. In contrast to simultaneity judgments, temporal anticipation of events seems to be comparable between adults with ASD and controls (Glazebrook et al., 2008). Another study reported impaired auditory but not visual temporal order judgments in children with ASD (Kwakye et al., 2011), whilst a study measuring preferential looking at asynchronous stimuli found a deviant looking pattern in young children with ASD (mean age of 5), but only when linguistic stimuli were used (Bebko et al., 2006). Overall, performance on event timing tasks in ASD seems to strongly depend on task requirements and the modality tested.

Interval timing refers to the judgment of explicitly attended duration, which can be tested using a wide range of tasks, including duration reproduction, production, discrimination, bisection and generalization. Importantly, interval timing depends on the activation of the timing mechanisms while a person is making time judgements. Studies on interval timing in ASD have yielded mixed results, uncovering either intact (Gil et al., 2012; Jones et al., 2009, 2017; Mostofsky et al., 2000; Wallace and Happé, 2008) or abnormal performance in individuals with ASD (Allman et al., 2011; Brodeur et al., 2014; Falter et al., 2012b; Karaminis et al., 2016; Kargas et al., 2015; Maister and Plaisted-Grant, 2011; Martin et al., 2010; Szelag et al., 2004). Several studies reported less accurate and more variable duration reproduction in ASD (Maister and Plaisted-Grant, 2011; Martin et al., 2010; Szelag et al., 2004), whereas one study reported increased accuracy of duration reproduction in children with ASD (Wallace and Happé, 2008), which might be due to task specificities (Falter and Noreika, 2014). A decreased sensitivity and at the same time increased consistency of time judgments across different intervals and modalities was found in adults with ASD using a temporal generalization task (Falter et al., 2012b). Similarly, a reduced sensitivity to interval timing in ASD was found using a temporal bisection task (Allman et al., 2011; Brodeur et al., 2014). While two studies reported decreased duration discrimination in the ASD group (Karaminis et al., 2016; Kargas et al., 2015), other studies testing time bisection (Gil et al., 2012; Jones et al., 2017) and duration discrimination found no differences between ASD and control groups (Jones et al., 2009; Mostofsky et al., 2000). Thus, again performance on

interval timing tasks in ASD might depend on task specificities and sampling.

While interval-timing tasks involve prospective estimation of durations, i.e. forewarning participants that they will be asked to estimate the duration of an event, retrospective timing judgements are made when a person is unexpectedly asked to estimate the length of time between two events. As such, retrospective timing relies on the storage of memories rather than an internal estimation of passing time, making it mechanistically different from interval timing (Wearden, 2005). While retrospective timing has been tested in another developmental disorder, attention-deficit/hyperactivity disorder (ADHD; McGee et al., 2004), we are unaware of any studies investigating it in ASD.

The third class of timing functions can be broadly referred to as temporal perspective, i.e. an ability to relate past, present and future in everyday tasks and reasoning, including a capacity to derive useful conclusions from the past experiences as well as an awareness of the future consequences of current decisions and actions. Temporal perspective can be studied using computerized tasks, such as delay discounting, standard questionnaires, and interviews. Preliminary observations indicate that individuals with ASD might have impaired temporal perspective, e.g. impulsivity is a frequent problem in ASD, which could be related to delay intolerance (Whiting and Dixon, 2015). Anecdotal and qualitative evidence suggests that individuals with ASD have an altered experience of the flow of time (Gepner and Féron, 2009) and their own temporal perspective in it (Ribeiro Zukauskas et al., 2009). Children with ASD were also found to show deficits in diachronic thinking, i.e. the abilities to perceive links between the past, present and future, to understand that events evolve through time, and to conceive successive events as one entity (Allman et al., 2011; Boucher et al., 2007).

Overall, the reviewed literature presented above leads to a twofold conclusion that calls for further research. Firstly, there is preliminary evidence of temporal processing abnormalities in ASD in all domains: motor timing, perceptual timing, and temporal perspective. In addition, individuals with ASD have disrupted circadian rhythm and sleep/wake cycles, including a delayed sleep-wake phase (Baker and Richdale, 2017) and frequent nocturnal awakenings (Schreck et al., 2004), which has been linked to abnormal melatonin synthesis in ASD (Melke et al., 2008). Secondly, and generally in line with perception studies in ASD (Falter, 2013), findings are inconsistent and different studies report impaired, intact or superior timing in ASD. Arguably, many of these inconsistencies could be attributed to the diversity of behavioural and perceptual profiles that fall within the autistic spectrum and to sampling and diagnostic differences across studies. Importantly, it remains unclear whether temporal processing abnormalities can be found across functions within individuals, converging to a generalised temporal processing deficit in ASD.

### 1.1. Aims of the study

Given that experimental studies are typically restricted to a single timing function, it remains difficult to identify the relationship between key temporal abnormalities in ASD, and determine whether there is a generalized timing deficit that spans across several timing functions. To address these issues, we used a battery of timing tasks, investigating different time scales and functions, in a single sample of participants. This design allowed us to assess which timing functions stand out as the key timing impairments, whether different timing tasks are inter-related in individuals, and whether they are associated with ASD symptoms.

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