Time perception in Autism Spectrum Condition: From psychophysics to everyday life contexts

A thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Biology, Medicine and Health

2020

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Contents

Word count: 58906

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Abstract

This thesis investigated whether and how time perception processes are affected in autism. More specifically the aim of this work was to characterise the perception of durations in autistic adults without learning disabilities. To this aim, the thesis followed three consecutive steps. First a systematic review of time perception studies in autism was conducted. Then, an online study in general population researched whether interval timing abilities were associated with the presence of autistic traits. Finally, a cross-sectional study was carried out comparing autistic adults and typically developed individuals across different time perception abilities.

The systematic review presents the research that has been conducted of time perception in autism through a taxonomy that classifies the time perception processes according to the cognitive complexity that the different tasks entail. This taxonomy has three main levels: (a) temporal sensitivity; (b) interval timing; and (c) higher-level time processing. Results show that increasing the complexity of the tasks in terms of their cognitive demands, also increase the consistency between studies showing impairment in autism. From the analysis of the literature it cannot be inferred that there is a generalised time perception impairment in autism or an impairment in their internal clock.

Chapter 3 shows the results of two online studies about the relationship between interval timing and autistic traits in general population. The first experiment used a verbal estimation task, where participants were asked to estimate durations of auditory stimuli. In the second experiment the participants completed a temporal generalisation task (and a pitch version as a control task), were they needed to remember the duration of a reference auditory stimulus and compare it with the duration of a series of comparison stimuli. Additionally, both experiments included

a retrospective time task and a questionnaire of autistic traits (Autism Quotient Abridged). The results of these experiments suggest that autistic traits do not exert an effect in neither the estimation of durations, memory for durations, or the retrospective time judgements.

The cross-sectional study (Chapter 4) involved experiments comparing time perception abilities between an autistic sample and a neurotypical sample. Each experiment represents each one of the levels of the taxonomy presented in the systematic review. All participants completed the same three experiments and a battery of questionnaires and tests assessing other cognitive functions such as IQ, working memory and executive function. The Experiment 1 investigated time sensitivity through an auditory temporal sensitivity threshold task. The Experiment 2 used temporal and pitch generalisation tasks. Finally the Experiment 3 compared the two groups in their Time-Based Prospective Memory abilities. Altogether the results of the three experiments show no evidence of time perception impairment in autism.

The evidence presented in this thesis consistently showed that autism spectrum condition is not characterised by an impairment in the perception of durations. Atypical perception of durations can be observed at an individual level, but this is true regardless of whether someone is autistic or not. More research is needed to understand and specify the processes underlying the phenomenological accounts of autistic people who express difficulties with time perception.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning

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Acknowledgement

This thesis counted with the cooperation from researchers, co-workers, and friends, whose support was very important at different stages of the development of this work. First of all I would like to thanks my main supervisors Dr Luke Jones who along with introducing me to the scientific research of time perception and showing me a new perspective for human cognition research, supported me with a very nice balance between freedom and guidance. This work is the consequence of opening the door to what at that time was only a curious student (that's not a metaphor; thanks for open the door!). I also want to thank the thorough and methodical guidance of Dr Emma Gowen (who I also knocked the door and who also answered!), Dr Ellen Poliakoff and Dr Daniel Poole, who helped me from the beginning to turn my initial scientific curiosity into a scientific work. Their constant guidance in all the technical aspects of this thesis was crucial, but also (and maybe even more important) their permanent support and understanding of what I'll refer here as 'the human aspects of a postgraduate researcher', was a key to bring this work to an end and enjoy the process. I would also like to highlight the contribution of Dr Daniel Poole, with whom I shared the data collection of the lab-based study presented in this thesis (and some exciting methodological discussions, squash games and crop growing technics). I also want to acknowledge the pastoral role from my advisor Dr Filippo Varese, whose advices will keep impacting future decisions.

I also want to thank Magdalena Besser who encouraged me to pursue this PhD in the beginning of our journey to the UK. Her love, patience, unconditional support and understanding were very important throughout these years, helping me (amongst other things) to have a good work–life balance. In a very closely related acknowledgement I want to thank ‘Wormito’ who has brought me a lot of happiness in the last part of this process.

I would also like to thank my family who always unconditionally supported my decision to pursue a Ph.D. Many friends have been present and have contributed to this thesis in different moments. The countless discussions with Francisco Jaume; the encouragement to pursue a science career from Dr Salas and Dr Radovic; the sense of family warmth of the family Mantelli – Montt; the reliable availability and the laughter from the families Valdivieso – Salinas, and Molina – Verdugo; and so many others that have been present and have offer their honest and disinterested friendship during these years.

Finally, I want to thank and acknowledge the funding bodies supporting this work. Thanks to the Presidential Doctor Scholar award scheme, that trusted on my abilities to pursue a science career, and to the ESRC that has supported the development of this work.

Preface

This thesis was initially motivated by a question that arose from the author's clinical practice. So, this preface is initially dedicated to generally describing that clinical experience in order to provide the reader with the clinical context in which this research idea was initially motivated. After the presentation of that context, a brief description of what is covered in the different chapters of this thesis is presented.

If the reader has a general knowledge of common interventions and guidelines when working with autistic people, he/she may know that one of the most usual recommendations for professionals, teachers, relatives, and caregivers is to prepare the autistic individual before executing any change in his/her environment in order to avoid behavioural crisis (*meltdowns*) or elevated amounts of anxiety. It is not uncommon that these 'action preparation cues' use time concepts to explicit when things would change. For example, common instructions to prepare a near future event could be "we leave in *two minutes*", or "your next activity starts in 5-minutes". However, these instructions are not always effective as preparations cues. That was the case of the patient AS, whose mother commonly used instructions similar to those in the examples, but the preparation act was ineffective and the anxiety response in AS triggered anyway.

To understand why the mother of AS was not effective in her attempts to prepare AS before changes, it was proposed to the mother that maybe they did not have a shared understanding. A possible source for this *misunderstanding* was that they did not have the same meaning of the temporal cues. So, for a few weeks training was conducted with AS to learn how long two-minutes and 5-minutes actually are, working with sand-clocks. Although there were no measurements pre-post, the experience was positively evaluated. Nevertheless, it was not possible to know if the change was due to improving the shared understanding of *two-minutes/five-minutes* or because of an improvement in the consistency of the time cue and the behaviour of the person giving that instruction (in this case the mother of AS). However, this possibility of improving social behaviour by training a variable related to time perception was an intriguing idea. So, the first question that needed to be tackled was whether autism is characterised by impairment in time perception. This thesis is the result of that initial question.

This thesis follows a Journal format, since the initial plan sketched to address the question about Time perception in Autism involved consecutive steps that give place to different products (journal articles). As the reader will see, these 3 steps are independent articles that complement each other, but also follow a logical order and increase in complexity according with my development as a researcher throughout the PhD program. The methodology employed in each article is explain in the *Material and Methods* section of each in detail, and the critical reflection about these methods can be found in the *Discussion* section of each article and the General Discussion of the thesis.

The first chapter of this thesis offers a general background on autism and time perception. Firstly, the main theories of autism are presented along with evidence regarding its aetiology, diagnostic criteria, and evidence of sensory atypicalities in autism. Then a general background about time perception research, including a brief description of the main models and properties that govern this cognitive process are presented. Chapter 2 presents a published Systematic Review about time perception in autism spectrum condition (Casassus et al. 2019). Chapter 3 is a presentation in journal paper format of an online study conducted in the general population measuring interval timing and autistic traits, which involved two different experiments. Chapter 4 compares a sample of autistic and neurotypical individuals in three different experiments using different time perception tasks, from the psychophysical to more ecological assessments. Given the large battery of assessments conducted in this chapter. Finally a general discussion is presented with the main conclusions of the thesis, its limitations and future directions. Each chapter has its own list of references (because they are individual articles), but adittionally a full list of references of the thesis is presented at the end of the thesis.

1. Chapter 1: Introduction

1.1. Autism Spectrum Condition

1.1.1. Defining Autism Spectrum Condition

Autism Spectrum Condition (ASC) is a neurodevelopmental condition characterised by impairments in social communication and interaction, and repetitive and restricted behaviour and interests (DSM-V; American Psychiatric Association [APA], 2013; Table 1.1). These two main components in the diagnostic criteria are often referred as the social and non-social atypicalities of ASC. The social component can be observed in verbal or non-verbal communication, and it can be present in restricted social contexts. One of the non-social impairments is the presence of sensory atypicalities that can fluctuate from hyper- to hypo-sensitivity (i.e. increased or decreased sensitivity to some stimuli that can be present in different sensory modalities). Although the main components in the diagnostic criteria have remained since its first appearance in DSM-III (1983), the somewhat unclear boundaries of the spectrum and wide range of comorbidities and functional levels, keep encouraging researchers and clinicians to review and question the theories and causes explaining the condition.

One of the first points on which researchers and clinicians have not reached an agreement is whether to define the spectrum as disorder or condition (even some professionals use both depending whether they are working in a diagnostic or therapeutic process). The term Autism Spectrum Disorder is the concept used in the DSM-5 (although its use precedes it) as an answer to clinicians' predilection of person-first language, and defining the individual as having a disorder and not being a disorder (Kenny et al. 2016). However, autistic individuals without learning disabilities are difficult to define as having a disorder and they (and their relatives) often feel offended by the pathological characterisation. Because this thesis worked with autistic adults without learning disabilities, the current document makes use of the term, ASC instead of ASD, and *autistic individuals* instead of *people with autism*, so it is conceived as a neurodiversity instead of a neuropathology (for a discussion about whether autism is a neurodiversity or a disorder, see Baron-Cohen, 2017).

Table 1.1: DSM – 5 Diagnostic criteria for Autistic Spectrum Disorders

A. Persistent deficits in social communication and social interaction across multiple contexts, as manifested by the following, currently or by history (examples are illustrative, not exhaustive, see text):

1. Deficits in social-emotional reciprocity, ranging, for example, from abnormal social approach and failure of normal back-and-forth conversation; to reduced sharing of interests, emotions, or affect; to failure to initiate or respond to social interactions.

2. Deficits in nonverbal communicative behaviours used for social interaction, ranging, for example, from poorly integrated verbal and nonverbal communication; to abnormalities in eye contact and body language or deficits in understanding and use of gestures; to a total lack of facial expressions and nonverbal communication.

3. Deficits in developing, maintaining, and understanding relationships, ranging, for example, from difficulties adjusting behaviour to suit various social contexts; to difficulties in sharing imaginative play or in making friends; to absence of interest in peers.

B. Restricted, repetitive patterns of behaviour, interests, or activities, as manifested by at least two of the following, currently or by history (examples are illustrative, not exhaustive; see text):

1. Stereotyped or repetitive motor movements, use of objects, or speech (e.g., simple motor stereotypies, lining up toys or flipping objects, echolalia, idiosyncratic phrases).

2. Insistence on sameness, inflexible adherence to routines, or ritualized patterns or verbal nonverbal behaviour (e.g., extreme distress at small changes, difficulties with transitions, rigid thinking patterns, greeting rituals, need to take same route or eat food every day).

3. Highly restricted, fixated interests that are abnormal in intensity or focus (e.g, strong attachment to or preoccupation with unusual objects, excessively circumscribed or perseverative interest).

4. Hyper- or hypo reactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement).

C. Symptoms must be present in the early developmental period (but may not become fully manifest until social demands exceed limited capacities, or may be masked by learned strategies in later life).

D. Symptoms cause clinically significant impairment in social, occupational, or other important areas of current functioning.

E. These disturbances are not better explained by intellectual disability (intellectual developmental disorder) or global developmental delay. Intellectual disability and autism spectrum disorder frequently co-occur; to make comorbid diagnoses of autism spectrum disorder and intellectual disability, social communication should be below that expected for general developmental level.

An issue that has occupied much attention from researchers and clinicians is the aetiology of the ASC. A large number of both genetic and environmental risk factors have been identified to be associated with ASC (Fakhoury, 2015), suggesting that the aetiology of the condition is highly heterogeneous (Greyson and Guidotti, 2016). A remarkable feature in the genetic studies in ASC is that in the whole set of genes associated with autism, almost half of them are not heritable (Figure. 1.1) (Hughuet et al. 2016). This heterogeneity in the causes and risk factors fits with the wide variation in the severity of the symptoms and comorbidities, which is the major reason for what ASC has been proposed to be a continuum of symptoms in both social and non-social atypicalities (Kronke et al. 2016. Consequently, researchers and clinicians continue to work on gaining a better understanding of ASC, possible causes and the diagnosis precision (e.g. Constantino and Charman, 2016, for a discussion about development and future directions in the diagnosis).

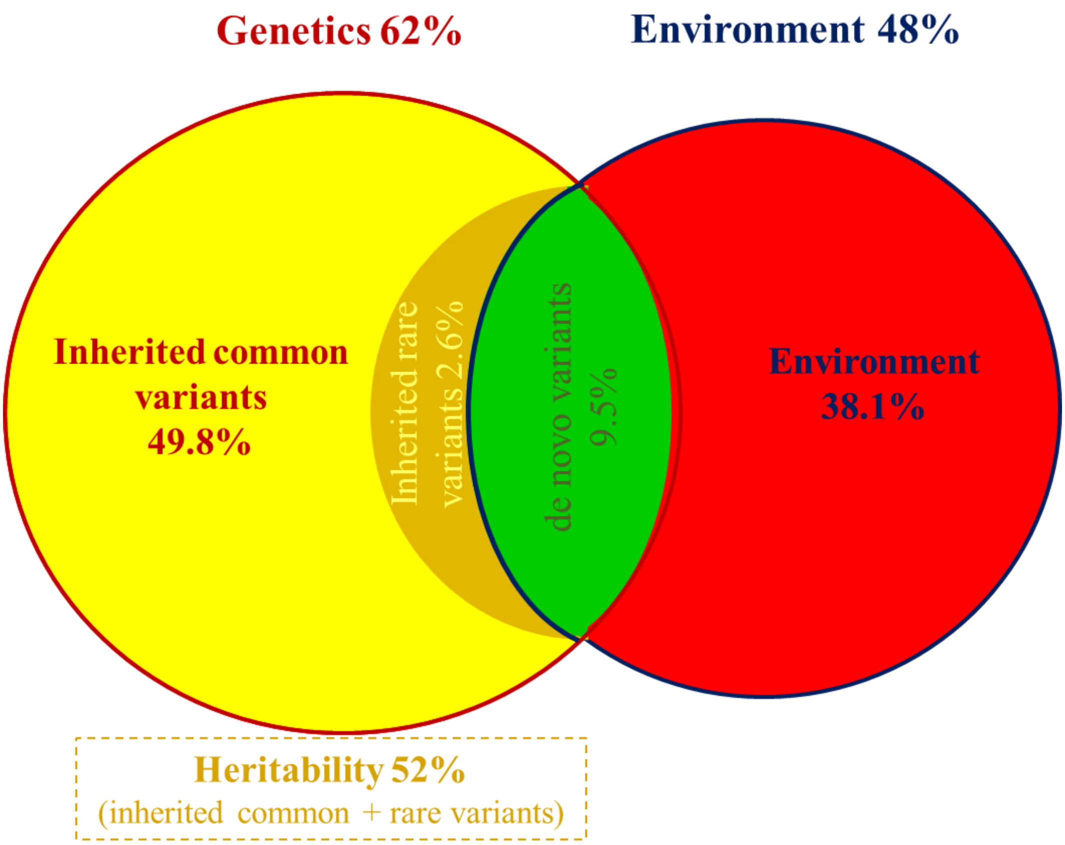

Figure 1.1: Relative contribution of genetic and environmental factors explaining the great genetic variability and how genetic and environmental factors contribute to the condition at a rate of almost 1:1. Despite this huge heterogeneity it has been shown that many of these genetic modifications have effects in the same sort of neural pathways (modified from Huguet et al. 2016).

There is no agreement among researchers about how social and non-social symptoms in autism are mapped onto each other. Happe and Fritz (2006) suggest that social and non-social symptoms could be to some extent independent, although they acknowledge that they can influence each other. This idea of social and non-social atypicalities as independent processes has been suggested in genetic research, where it has been proposed that these atypicalities can be dissociable even at a genetic level (Warrier et al., 2019). Gowen and Hamilton (2013) proposed as future line of research to study the relationship between motor and social difficulties in ASC, which suggests that there is a relationship between motor and social skills that is under-researched. A possible strategy to tackle this issue has been suggested by Bolis and Schilbach (2018) who after reviewing perceptual and social difficulties in autism suggest to incorporate more ecological or 'real life' paradigms into research protocols, where the measurements of specific abilities (motor, sensorial or cognitive) could be applied in social context.

An important issue regarding the heterogeneity of ASC are the wide variety of comorbidities associated with it. A study in 160 ASC children and adolescents (including autism, Asperger and pervasive developmental disorder) showed that only 12% did not have comorbidities, with the remaining 88% having at least one of the following: sleep disorders, food intolerance, gastrointestinal dysfunction, epilepsy, mood disorders, and aggression (Ming, Brimacombe et al. 2007). In addition, ASC overlaps symptoms for many neuropsychiatric disorders, like mood disorders, schizophrenia, personality disorders and obsessive compulsive disorder (Vannucchi et al. 2014). In terms of intellectual abilities (measured from available IQ score data), the Center of Disease Control and prevention, showed that among 3390 children 31.6% matched criteria for intellectual disabilities, 24.5% for borderline intelligence, and 43.9% for average or above average intelligence (Christensen et al. 2012). Thus, the heterogeneity of symptomatology, deviant behaviours and atypicalities in autism, is a permanent challenge for both research and treatment.

In summary, ASC involves a wide and heterogeneous range of social and non-social symptoms that can be accompanied by different comorbidities. Taking into account the wide range of genetic and environmental factors, there is no clarity about whether the different levels of functioning within the spectrum are all part of the same condition or different conditions with unspecific symptomatology.

1.1.2. Neurobiology of ASC

A highly accepted idea in neurobiological and neuropsychological research is that any behaviour needs a biological structure that supports that behaviour (the structural determinism of the function hypothesis). As such, the behavioural differences reported in ASC should be underpinned in some way by structural differences in their neurobiology. Consequently many studies have tried to characterize ASC from the neurobiological perspective using neuroimaging and electrophysiological techniques. The outcome of these efforts is a huge amount of research that has produced different findings and hypotheses but little in the way of certainties; probably because of the wide heterogeneity of the condition and the differences in the developmental trajectories across the condition. The following section gives an overview of some of the most accepted neurobiological theories explaining ASC.

Neuroimaging studies have attempted to localize which brain structures are compromised in ASC. Pua, Bowden and Seal (2017) reviewed 12 systematic reviews of neuroimaging studies in ASC, finding a high variability across studies. The authors highlight the variation of findings during lifespan in both gray and white matter abnormalities. These differences between results in neuroimaging studies in ASC at different ages have also been reported by Riddle, Cascio and Woodward (2017), who showed that the increased grey matter volume observed in childhood does not remain when analysing adulthood data. In addition, there is a well-documented association between autism and aberrant patterns of neural connectivity, in comparison to neurotypical population. Picci, Gotts and Scherf (2016) reviewed the evidence in favour and against the over/under connectivity hypothesis in ASC. Based on resting state fMRI studies (which they found to be the most consistent technique across studies) they suggest that under-connectivity between cortico-cortical regions; over-connectivity between subcortical-cortical regions; and compromised tracts in the temporal lobe, seem to be a peculiarity in ASC. In addition, they encourage future studies to pay extra attention to developmental trajectories and individual differences. Related to the connectivity findings in ASC and the differences during development, Frith (2003) hypothesized that the higher number of neural connections observed in ASC could be explained by a lack of neural pruning process. In the same line, Baron-Cohen (2017) suggests that the increased number of neurons in the frontal lobe shown in post-mortem studies could be due to reduced apoptosis. Nevertheless, the evidence using neurodevelopmental approaches is still scarce.

Complementary to fMRI studies, studies using EEG (electroencephalography) and MEG (magnetoencephalography) were systematically reviewed by O'Reilly, Lewis and Elsabbagh (2017) finding (again) a huge heterogeneity of methods and results. They concluded that functional connectivity in ASC adults is abnormal in frontal and occipital regions, even though they acknowledge that studies with results describing connectivity atypicalities can be found in many other brain regions. In terms of frequency bands, O'Reilly et al. (2017) propose that under-connectivity in autism is more associated with low-frequency bands (delta – beta: associated with long range networks; and over-connectivity with high-frequency bands (beta – gamma: associated with local range networks). Finally, these authors highlight the importance that individual differences and developmental trajectories for future approaches.

Another neurobiological approach to explain ASC is a possible GABA/Glutamate imbalance, so between the primary inhibitory and excitatory neurotransmitters.

According to the Excitatory/Inhibitory Imbalance Theory (EI theory), this imbalance would explain symptomatology in ASC (Rubenstein and Merzenich, 2003; Dickinson, Jones, Milne, 2016). A meta-analysis conducted by Schur et al. (2016) about GABA levels across different psychiatric disorders, showed that the evidence of lower GABA level in ASC was more consistent than the evidence for other psychiatric conditions (e.g. Schizophrenia). However, Dickinson et al. (2016) explain that the direction of this imbalance is not entirely clear, probably because different methods have been employed to test this theory. Additionally, these researchers suggest that the imbalance shown in ASC could be differently expressed in different brain regions and in possible different subtypes of autism within the spectrum.

In summary, many studies using very different methodological approaches have tried to characterise ASC in its neurobiological features, giving rise to a number of different hypotheses to explain the condition. However, as most of the systematic reviews in the area highlight, the heterogeneity of the condition and variability of the neurobiological characteristics in possible subtypes of ASC and throughout development, make it difficult to draw firm conclusions.

1.1.3. Sensory and motor impairments in autistic adults

Among the non-social atypicalities in ASC, several studies have paid attention to differences in sensory and motor abilities. There are many consequences of these atypicalities in everyday life, like finding the world confusing and overwhelming across different sensory systems (e.g. hypersensitivity to some noises such as motorbike engines or vacuum cleaners). Although in the awareness and control of these atypicalities they may sometimes experience enjoyment (Jones et al. 2003).

In the sensory domain, studies have shown that autistic individuals present difficulties in perceiving, integrating and modulating their sensory experience in different modalities, but there is a huge heterogeneity regarding the specificity of such difficulties (Uljarevic et al. 2017). For example, studies have reported hypersensitivity in autism for auditory modality, but no differences in tactile sensitivity (O'Riordan and Passeti, 2006). Those findings are supported by other studies showing no differences in tactile sensitivity thresholds (Cascio et al. 2008) and hypersensitivity for the auditory modality (Gomot et al. 2002). A review about auditory abilities in autism concluded that atypicalities in this modality are a characteristic feature of the condition, and that these abnormalities were more present in complex-speech stimuli than non-speech stimuli (O'Connor, 2012). Atypicalities in visual perception and bimodal perception have also been reported in neurophysiological measures (see Marco et al., 2011 for a review). A study of 200 children and adults, found a 90% of presence of sensory atypicalities in at least one of the following: audition, vision, tactile processing, smell/taste, other oral atypicalities, kinaesthetic, and pain (Leekman et al. 2007). A better understanding of the sensory atypicalities and the behaviour in autism often described as *disruptive* can be highly beneficial in improving the quality of life of autistic individuals and their caregivers (Jones et al. 2003).

Motor atypicalities in ASC are also highly prevalent (Ming et al., 2007), including among others coordination, gestures, imitation, and abnormalities in muscle tone (Hilton et al. 2011). These atypicalities are so widespread within the spectrum that it has been suggested that they should be included in the diagnostic criteria (Constantino and Charman, 2016). A review by Gowen and Hamilton (2012) concluded that autistic people have abnormal high-order sensory processing, overreliance on proprioception during process of sensory-motor integration and difficulties in motor planning activities (requiring more time). The authors concluded that autistic people seem to have issues integrating motor information with other systems, but they are not impaired in what they called the "underlying motor machinery".

1.1.4. Cognitive theories of ASC

1.1.4.1. Weak central coherence

The weak central coherence theory proposes that human beings tend to process incoming information as a whole, picking up different details and combining them into a coherent emerging understanding (Van der Hallen et al. 2014), a process that implies a comparative detriment for details (Happe and Frith, 2006). In other words, the human brain integrates the activity from different sensory systems and memory into a coherent whole (or Gestalt), in preference to attending to each separated detail. This theory explains the non-social impairments in ASC as consequence of having a bias to perceive details, as opposed to perceiving this 'whole picture' (Happe and Frith, 2006). These authors explain that the central coherence would be a normally distributed ability, with autistic people being situated at the detailed extreme of that distribution, and that even though someone can be located in one of the extremes of this distribution, they can perform with the opposite style if instructed. For example, an autistic individual (detailed focus style) could perform as someone with strong central coherence, if they were explicitly instructed to do so.

An issue that is still in the debate among researchers supporting Weak Central Coherence theory is whether this bias-to-details style is because of enhanced detail processing or impaired global processing (or both). As shown by a review from Happe and Frith (2006), the evidence seems to be more consistent in terms of ASC people having enhanced local processing rather than weaker global processing. A meta-analysis about visual processing conducted by Van der Hallen et al. (2014) concluded that autistic people required more time when processing global information, and they use a local processing style in tasks where Neurotypical individuals (NT) tend to use a global processing style. A study from Booth and Happe (2016) working with a visual integration task, showed that autistic people had decreased global processing, but not enhanced local processing, suggesting possible independent processes. Some of the problems separating global and local processing are task related, so the design of specific tasks for each process and analysis of individual performance in these tasks have been proposed for future research (Happe and Booth, 2008).

1.1.4.2. Bayesian accounts explaining ASC: Hypo-priors and predictive coding.

In 2012, an opinion article by Elizabeth Pellicano and David Burr presented a new hypothesis to explain the atypicalities in autism. These authors proposed that autistic people perceive the world in a less biased way because they do not use their priors (information from previous experiences) as the neurotypical population does, and consequently they have a hypo-priors style of perception. This different style would be supported by more reliance on bottom-up processes, instead of more reliance on top-down processes in NT (Pellicano and Burr, 2012). The hypersensitivity and hyposensitivity often reported in autism would be the result of this hypo-priors style, as autistic people would not be integrating real-time sensorial experience with previous experience (memory), making it difficult to create an expectation of the stimulus with which they are interacting (Pellicano and Burr, 2012).

An alternative explanation using the Bayesian framework as reference is predictive coding. Van de Cruys et al. (2012), agreed with the usefulness of the Bayesian framework to explain the atypicalities in autism, but they hypothesise that instead of a lack of, or reduced priors, rather strong and inflexible priors (not transferable) between contexts would explain the differences in perception in autism. In other words, autistic individual would fail when they attempt to apply predictions about a particular stimulus in one particular context, to another context or stimulus. Similarly, Friston et al. (2012) hypothesise that the observations supporting the weak central coherence theory in autism could be explained by the lack of priors as well, as this would be a failure of metacognition because it would be "a failure of beliefs (estimated precision) about beliefs (predictions)" (Friston et al. 2012, pp.1).

1.1.4.3.Theory of mind

Theory of Mind (ToM) is a conceptualization that describes the mentalization processes of attributing beliefs, intentions and emotions to one-self and to others, an ability that is highly relevant when making predictions about other's behaviour (Premack and Woodruff, 1978). In the case of autism, this theory focuses on the social atypicalities and suggests that autistic individuals have problems representing the mental states of others, and as a consequence a difficulty in predicting behaviour in others (Baron-Cohen et al. 1985). This deficit in the ability to infer mental states of others has been proposed as one of the main features of autism (Baron-Cohen, 2000) and to be independent of cognitive deficits (Baron-Cohen et al. 1985). However, other studies comparing basic (sincere interaction) and advanced theory of mind (such as sarcasm and deception) have suggested that the impairments are only present in the advanced theory of mind abilities (Mathersul et al. 2013). In addition, evidence from neurotypicals with autistic traits (subclinical autistic-like behaviours/symptoms – Constantino and Todd, 2003) has shown a negative correlation between ToM abilities and autistic traits (specially in individuals with lower IQ), thus it is has been suggested that cognitive abilities play an important role in the mentalizing abilities required in ToM tasks (Gokcen et al. 2016). The possible problems with theory of mind encountered echoes in the mirror neurons system (MNS). The MNS has been proposed as the neural mechanism underlying imitation (Williams et al., 2001) and other social behaviours (Iacoboni and Dapretto, 2006). So, the MNS has been proposed as a possible neural explanation underpinning the deficits in autism (Williams et al., 2001), especially in what concerns their problems with ToM, imitation, pragmatic language and empathy (Oberman and Ramachandran. 2007). However, the current evidence is contradictory. In fact, imitation has been found unimpaired in autism in goal-directed imitation (Wild et al., 2012). So the evidence is not strong enough to support a broken mirror neuron system as the only mechanism explaining the problems with ToM (See Hamilton, 2013 for a review).

1.2.Time Perception

Defining time perception is not an easy task because it is not a unique process, but a range of different (although likely related) abilities regarding the temporal characteristics of stimuli and events in both the environment and memory. *Time perception* is arguably an inaccurate and confounding term, because time perception does not share the main requisites that classically define a proper perception. A perception is characterised by the resulting cortical activity after the propagation of the activity from excited specialised receptors (as happens for example in vision, audition, tactile system, etc.; Kandel and Mack, 2013). There are obviously no receptors for time. Nevertheless, the level of acceptance by use is so widespread, that most of the researchers in the field keep using it. Researchers in the disciplines of experimental psychology and cognitive science have focused their attention on a wide range of behaviours; from the study of sensitivity to durations, to the temporal order of events in long-term memory. However, the evidence about how the different time-related behaviours are related is scarce. One of the areas of study that has received more attention is the perception of duration, which is the study of the temporal characteristics of stimuli and events (and the focus of this thesis), i.e. how we perceive how long a stimuli or event lasted for.

Different models have been proposed to explain how humans (and animals) perceive durations, but they can be grouped in what Ivry and Schlerf (2008) refer to as dedicated and intrinsic models. Dedicated models are those that propose a specific system to perceive durations, while intrinsic models postulate that *durations* are an intrinsic dimension of the neural activity within the sensory systems, and so there would be no specific mechanism in the brain exclusively dedicated to the perception of duration. The aim of this subsection is to give a general overview of the main models of time perception. The first model presented (Scalar expectancy theory) receives more detailed attention since is the theoretical framework on which the subsequent chapters are based. More details regarding time perception processes and the tasks used for studying this process are also given in the following chapters.

1.2.1. Main Models of time perception

1.2.1.1.Scalar Expectancy Theory

One of the most accepted models about how individuals judge durations is Scalar Expectancy Theory (SET), first developed from studies in animal timing by Gibbon (1977; et al. 1984) and the subsequent work of Wearden (1991, 1992) who adapted the theory to model to human performance. Basically, the model consists of three stages: (1) a pacemaker-switch-accumulator clock, (2) memory stages, and (3) a decision-making process (Figure 1.2). As is explained by Wearden, Williams and Jones (2016), if someone were attempting to assess the duration of a determined stimulus or event, the internal clock would produce pulses (they might be thought of as ticks, clicks, pulses or even neural spikes), which would be stored by the accumulator, connected to the pacemaker by a switch (that would be activated depending on attention). The quantity of pulses in the accumulator would be the so-called raw material for duration judgements. Then, in the memory stage, this accumulated pulses in short memory (working memory), would be compared with previous experiences with durations, or Long Term (usually termed Reference) Memory. Finally, a decision-making process decides how long the duration was.

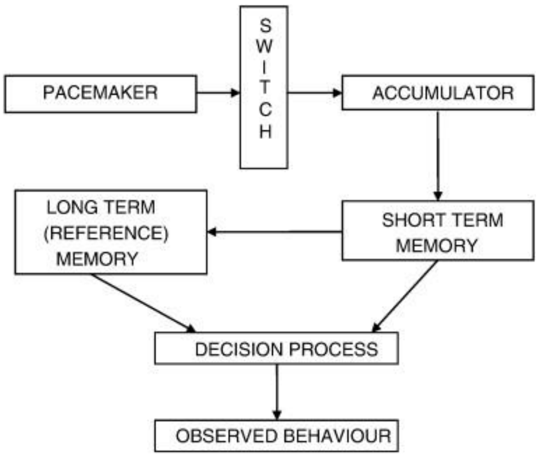

Figure 1.2: Scalar Expectancy Theory (Gibbon et al., 1984).

A key component of this model is its adjustment to the *Scalar Properties* of timing: *mean accuracy* and the *scalar property of the variance*. As is explained in Wearden and Lejeune (2008) Mean Accuracy is the property by which the estimation of a given duration is on average equal to that given duration. So, the judgements of short intervals are in fact shorter than the judgements of long intervals, and the progression of the estimations of short-to-long intervals vary linearly according to the durations that are being estimated; e.g. if one doubles the duration then the estimates will also double.

The second property, the scalar property of the variance, refers to the observation that the variability of the estimated durations vary with the mean of those estimations (Wearden and Lejeune, 2008). In other words, the standard deviation of shorter estimated durations will be smaller than the standard deviation of longer estimated durations. So, this is basically a form of Weber's Law, where the standard deviation is a constant proportion of the mean (Wearden, 2016). One of the main methods to assess the scalar property of the variance in what is known as *superimposition*, which can be seen by bringing different duration ranges to the same relative scale (Jones and Wearden, 2004).

Although the scalar properties of timing constitute strong evidence to support SET, these properties can be violated in some tasks. Wearden and Lejaune (2008) discussed four factors than can cause violations to scalar timing: (a) use of very short durations; (b) the difficulty of the task; (c) estimation methods; (d) unusual variance patterns because of extensive training. From these, given their importance in the timing research in autism (and the aim of this thesis), point (c) is particularly interesting to discuss. Estimation methods involve tasks where participants estimate a given duration, and express their judgement by performing an explicit behaviour. The most common methods are time reproduction, production, and verbal estimation. In time reproduction the participant is presented with a stimulus (e.g. a tone) and is asked to reproduce its duration executing a motor behaviour (e.g. pressing a key). In production of duration, the participant is given a target duration in physical units (milliseconds, seconds, etc.) that they need to produce behaving in a predefined manner (e.g. pressing a key). Finally, in verbal estimation the participant needs to give an answer in temporal physical units, estimating the duration of a given stimulus (e.g. ‘that tone was 1000 ms’). In the reproduction task, the main issue is adding a motor response that is constant regardless of the duration of the interval-to-be-timed, affecting then the scalar properties. In the case of verbal estimation, individuals also tend to give *rounded* answers. For example, for estimations of 522 ms and 478 ms, they will tend to respond 500ms, a phenomenon called quantization that has obvious effects in the standard deviation of the estimations (see Chapter 3 for further explanation).

One of the criticisms often argued against SET model is that it is too flexible, allowing explanations for different contexts or tasks where its main properties are not fulfilled, making it very difficult to test by *falsification*. For example, some researchers claim that SET adapts the observations to the theory (SET), instead of building theory from the evidence (Allman, Penney and Meck, 2016). Additionally, it has been argued that SET lacks of neurobiological evidence underpinning their components, especially regarding the accumulator (Kononowicz, Van Rijn and Meck. 2020).

1.2.1.2.Striatal-Beat Frequency model

In an effort to fill the gap regarding the neurological basis of the perception of durations in the range of seconds to minutes, Mattel and Meck (2000, 2004) proposed the Striatal-Beat Frequency model (SBF). This model integrates a large body of neurobiological evidence of different brain areas involved in the perception of durations to suggest the neurological dynamics involved in the process. Thus, SBF is based on the thalamo-cortico-striatal loops, that has been shown to contribute to interval timing (Oprisan, Dix and Buhusi, 2014), and the coincidental activation of striatal spiny neurons (Buhusi and Meck, 2005; Konowicz, 2015). Importantly, this model is not an antagonist of SET, but a framework to describe from a possible plausible neurobiological explanation of what SET describes in a behavioural level (Buhusi and Meck, 2005).

A challenge acknowledged by researchers assuming this theoretical position is to be able to explain the perception of durations in the seconds range, from neural activity that works in a millisecond range (Oprisan and Buhusi, 2011). Basically, this theory proposes that the striatal spiny neurons integrate the synchronous activity from different brain areas in the prefrontal cortex (i.e. which would reset and synchronized on the onset of a trial) in periods that exceed the temporal range of the oscillations of those areas, so transforming an activity that is in a millisecond level (neural activity in the oscillators) into a wider range of durations (Oprisan and Buhusi, 2011). Metaphorically speaking, the synchronized oscillators in the brain areas would resemble a pacemaker, and the striatal spiny neurons would be a form of accumulator.

Different simulations have shown psychopharmacological manipulation of the brain areas implicated in SBF, showing scalar properties (Oprisan and Buhusi, 2011). However, the model still makes assumptions that need for stronger evidence – e.g. cortical oscillations reset at the beginning of a trial (Konowics and van Wassenhove, 2016). Also, as is acknowledge by Buhusi and Meck (2005), the proposed brain areas and circuity in which the perception of durations would be based, are known to be associated with several cognitive processes.

1.2.1.3.State-Dependent Network model (SDN): an intrinsic model for time perception

The State-Dependent Network (SDN) model proposes a completely different approach to the understanding of time perception that attempts to characterise this cognitive process from a neurobiological level. This intrinsic model claims that temporal information is part of the neural dynamics of the sensory systems, which would depict a spatial configuration of activity for one or another duration (Ivry and Schlerf, 2008). Thus, temporal information is encoded at a millisecond level as patterns of neural activity that constitute *temporal objects*, so as units that are not defined as linear metric of time (Karmarkar and Buonomano, 2007). Therefore, time information in the sensory system would not rely into an internal clock system.

The SDN model is based on neurons that show dynamics of short-term synaptic plasticity (STSP), affecting then the activity of those neurons which will respond in a time-dependent manner (a temporal response in accordance to the STSP) (Karkamar and Buonomano, 2007). This means that temporal information of a stimulus triggers a neural response with the corresponding STSP and by this, the temporal information is finally encoded in a spatial map of activity (Karkamar and Buonomano, 2007). Thus, two different durations would have a different spatially-mapped activity and individuals would learn to distinguish one pattern from the other. Consequently, it is proposed that this model is a contextual model, because the patterns of activity would vary depending on the sensory modality (i.e. different groups of neurons), and also depending on the previous experience of an individual with the tested durations (however, these properties would only be satisfied in a range of few hundreds of milliseconds (Karkamar and Buonomano, 2007).

One of the criticisms of the SDN model is that it does not satisfy the scalar timing properties, since it is nature is not based in a linear timing, but in a qualitative characterisation of the temporal characteristics of stimuli. In fact, the authors of this theory (Karkamar and Buonomano, 2007) acknowledge that learning these patterns is a key component of the model, which opens a question regarding how many patterns should be learnt to accurately discriminate between different durations.

1.2.2. Main tasks in Time perception research

1.2.2.1. Time sensitivity

Time sensitivity is the ability to distinguish the temporal characteristics of two stimuli that differ in their duration. Various methods (associated with different tasks) have been developed to describe temporal sensitivity. Because of their importance in time perception research in autism, this subsection concentrates on three methods: temporal sensitivity thresholds; simultaneity and temporal order judgements (SJ and TOJ respectively); and mismatch negativity (MMN) in electrophysiological approaches using event-related potentials (ERPs).

A temporal sensitivity threshold (or difference threshold) is the minimum difference in duration between two stimuli that can be discriminated. Sensitivity thresholds are believed to follow Weber's Law which is a lineal function that states how much stimuli need to differ as a function of the changes in the magnitude of those stimuli (Wearden, 2016). Thus, this point from which someone is able to discriminate between the duration of two stimuli, also called Just Noticeable Difference (JND) (Treutwein, 1995) changes in proportion with the increase in magnitude of the stimuli to be judged. A common method to identify sensitivity thresholds are Adaptive Methods, which are procedures where the characteristics of the stimuli vary as a function of the responses of the participant in order to rapidly find the sensitivity/difference threshold (Treutwein, 1995). A common adaptive method is the staircase procedure, where a standard duration is presented and the participant needs to compare it with a comparison stimulus. Each trial presents both stimuli in a randomised order and the participant needs to decide which one of the two stimuli is longer in duration. Then, every correct answer decreases the difference between the two stimuli on the next trial, while each incorrect response increases it. The ratio of the size of this step-up and step-down can be altered in order to determine the threshold at a particular percentage of likelihood, typically 75% (see Jones, Poliakoff and Wells (2008) for detailed explanation and example procedure). The task ends after 50 trials and the mean of the differences between the two stimuli on the last 20 trials is calculated as the threshold (Jones, Poliakoff and Wells, 2009). Other approaches in adaptive methods are the Parameter Estimation by Sequencing Testing (PEST) and the maximum-likelihood procedures (for a full discussion comparing the three methods see Leek, 2001).

A different dimension of time sensitivity is discriminating whether stimuli presented are presented simultaneously or successively. Thus, this time sensitivity process involves judging whether two stimuli are simultaneous, or if they preceded/succeeded one another. The tasks to measure this ability are SJ and TOJ, and the literature usually employs the term of temporal acuity (instead of sensitivity) (Poole et al. 2016).

Finally, ERP's have also been used to measure time sensitivity (Naatanen, 2004). The MMN component has been used as a measure of time sensitivity. This component is a negative direction wave observed when after a train of stimuli of the same kind is interrupted for a deviant (Luck, 2005). This negative direction wave commonly peaks between 160 – 220ms after the stimulus presentation and the component appears even if no attention is directed to the stimulus. Because the amplitude of the wave varies as function of the difference between the standard and deviant durations, the MMN component has been proposed as a measure that is coherent with Weber's Law (Brannon et al. 2008).

1.2.2.2.Interval Timing

Interval timing refers to the ability to make judgements about how long stimuli last for. Such judgements can be done prospectively, when you have been warned that the temporal judgement will be required; and retrospectively, when you do not know a temporal judgement will be required. Although some researchers have claimed that prospective and retrospective timing are closely related (French et al.

2014), prospective and retrospective judgements appeared to rely on different cognitive resources (attentions and memory respectively, Block and Zakay, 1997). Thus, different cognitive models have been proposed to support them.

1.2.2.2.1. Prospective timing

Making judgements about the duration of stimuli when you have been warned that such judgement would be required, involves (amongst other cognitive resources) paying attention to the duration of the stimuli. Different methods are used in prospective time research that can be grouped into two main clusters: (a) Comparison methods, that are characterised by the execution of a comparison of a standard duration with subsequent stimulus durations. The two most common tasks are *temporal bisection* and *temporal generalization*; and, (b) Estimation Methods, which involves an estimation of a given duration that is expressed by performing an explicit behavior (details earlier in this chapter when discussing SET and in Chapter 3). The most common assessments are time reproduction, production, and verbal estimation (for further details see Chapter 2).

1.2.2.2.2. Retrospective timing

Judging time retrospectively is closely related with memory processes of the event that initiated the duration to be judged and the qualitative and quantitative qualities of the events that occur between the initial event and the judgement. One of the most accepted models that have been developed for this type of temporal judgement is related with the cognitive load of the duration to be judged, where higher cognitive loads would be related with longer estimations of time (Block, 1992;

Hicks, Kinsbourne and Miller, 1976; Wearden, 2008; Block et al. 2010; French, et al. 2014).

A key methodological limitation that has meant that retrospective timing research is more scarce than prospective timing research is that retrospective questions can be done only once in each experimental situation. The reason for this is that after the participant answers the retrospective question, he/she would start paying attention to the elapsed time in case he/she is asked again, turning the retrospective judgement into a prospective one. Thus once can only obtain one trial from each participant, as such these studies typically use 100s of participants if they are to have any statistical power.

1.2.2.2.3. Time-based prospective memory and other High-order time processing

High-order time processing involves a cluster of abilities that are not purely a perception of duration, but that involve temporal judgements or uses of temporal abilities as a core component of other cognitive processes. So, the temporal judgements are presented within a context involving other cognitive processes, making difficult to disentangle the temporal judgement (when they are actually present) from these other processes. One of the most studied high-order temporal processing processes are passage of time judgements. These are judgements not of duration but judgements people make about how fast or slow time seems to pass in a given duration. Some common statements that seem to relate to this type of judgement are “this year is going so fast” or “Christmas comes round quicker every year”, some even sound like duration judgements such as “that lecture felt like it lasted for day”. Those statements can be metaphorical use temporal concepts to describe how people feel in a determined situation (e.g. having been extremely busy and engaged or extremely bored respectively), and currently we do not know if they are actually related with the perception of durations, or the reported experience in some pathological conditions (as brain injury), where people do not know how long they have been engaged in a particular task (for a deeper discussion about passage of time judgement see Wearden, 2015).

Another relevant high-order temporal process is Time-Based Prospective Memory (TBPM). This process is the ability to behave in some previously defined manner in some specific moment that is temporally pre-defined (Williams et al., 2013). For example, if someone is asked to pull a string in some artifact's mechanism, 7 minutes after the artifact has started its action. To accomplish this sort of task, people need to keep in memory the reference of how long seven minutes is, and maintain attention to the how much time has passed. This type of higher-order temporal processing in human behaviour seems important to social coordination, however, the specificity of how this process is related with the perception of durations (or other timing judgements discussed above) remains unclear. Hypothetically, the temporal references in memory should not be different from the reference memory component of SET used in duration judgements (this point will be more deeply covered in chapter 4).

Importantly, not all the prospective memory tasks involving a *temporal concept* involve a perception of duration in a *pure* sense. If someone asks you to turn on the oven when the clock marks 3pm, there is no perception of duration or temporal judgement involved. Basically, you are waiting for an external cue to be present in the environment, which is the handles of the clock showing 3pm. Although this example usually entails a clock checking based in a temporal estimation, it is not a pure time estimation, but a time monitoring task where the task is been affected by the extent to what the passage of time can be externalized by the individuals (Conte and McBride, 2018). A different scenario is when someone asks you to turn on the oven in 5-minutes without checking a time-aid device, which involves to self-monitor the passage of time and self-retrieve from memory when to execute the intended response (Block and Zakay, 2006). Some of the implications of this differences are later discussed in Chapter 4 and Chapter 5.

1.2.3. Time perception in neuro-diverse and pathological conditions

An important question about time perception is whether it is a cognitive ability that can be impaired as a specific type of disability. One of the first works attempting to characterise a clinical population in terms of its time perception atypicalities was a by Davidson (1941), who reported two cases of brain injury patients reporting what he called a syndrome of time-agnosia. Davidson's suggestion was that an enquiry of time abilities should involve five dimensions (factors): "1. appreciation of rhythm; 2. estimation of appreciation of short intervals of time; 3.appretiation of the flow of time; 4. appreciation of chronology; 5. Appreciation of past, present and future" (Davidson, 1941 pp. 337). However, to date there is no pathology, syndrome, or neurodiversity uniquely characterised by a time perception abnormality (e.g. the patients reported by Davidson had a whole set of comorbidities). Other works have tried to systematize abnormalities in time perception in psychopathological conditions (see Cutting and Silzer, 1990 for personal accounts in brain disease and schizophrenia), however most of the research in this area comes from the last 25 years. Binkofsky and Block (1996) resported a clinical case of brain injury in the patient BW, who suffered a lesion in the left frontal cortex. Although the patient showed good orientation in time, he reported what is known as a *Zeitraffer* phenomenon (an accelerated time experience similar to a time-lapse condition in a film), a temporal production task showed an average of 286 seconds even though the task required to produce 60 s. This observation led the authors to suggest that the pacemaker of BW was working in a decrease rate, because that could explain the poor performance in the temporal production task and the *Zeitraffer* phenomenon. This is an anecdotal clinical report that gave place to the hypothesis that traumatic brain injury (TBI) was characterized by a time perception impairment. However, a review conducted by Mioni et al. (2014) showed that the poorer performance estimating time often reported in TBI patients is due other cognitive processes (attention, memory and executive function), and not because a pure time perception impairment.

A group of conditions that have reached the attention of researchers in time perception are neurodegenerative disorders, especially Alzheimer's and Parkinson's disease. Although research has reported impaired time perception in Parkinson's disease (Smith et al. 2007), Wearden et al. (2008) found no differences in a group of 24 Parkinson's disease individuals and matched controls (once differences in motor timing had been controlled for). An interesting point in Wearden et al. study is the complete set of tasks used for the characterisation of time perception abilities, working with temporal thresholds, temporal generalization, temporal bisection, verbal estimation and memory or duration, which is unusual in time perception research in atypical conditions (e.g. autism. See Chapter 2). A meta-analytic review in Alzheimer's disease suggested that impairment in time perception tasks may be related to impairments in both attention and memory processes (El Haj and Kapogiannis 2016).

A systematic review and meta-analysis of time perception in Schizophrenia showed impairment in temporal order judgements and interval timing in terms of precision but not in accuracy (Thoenes and Oberfeld, 2017). Another systematic review conducted in individuals with Schizophrenia suggested that time perception impairment could be an endophenotype not only in schizophrenia, but also in Schizotypal personality disorder (Ciullo et al. 2016). Working in a wider set of psychopathologies and neurological conditions, Moreira et al. (2016) reviewed the literature on time perception research in impulsivity disorders, finding that impulsive people with brain injuries tend to underestimate time in reproduction tasks, although they acknowledge that time perception atypicalities are under-studied in this population and that in general the results are mixed. It is worth mentioning that the time reproduction task has been criticized because is a task that has been shown to have poor internal consistency (Marx et al., 2020).

To date there is no evidence of a generalised impairment as a characteristic feature of any pathology or atypical condition. However, evidence of impairment has been reported in different long-term conditions, and it seems that some populations are more vulnerable than others to present atypical time perception, as is been suggested in autism (Allman and De Leon, 2009).

1.3. Objectives and structure of the Thesis

As was explained in the preface this thesis is structured in three articles covering different levels of analysis about time perception in autism, having as main objective to characterise time perception processes in autism.

As will be shown in Chapter 2, one of the problems when reviewing the literature of time perception in autism (and in other long-term conditions), is that tasks measuring different processes are clustered together as if *Time Perception* would involve only one and well delimitated process (which is not the case). So, it is not clear at what level and to what extent the atypicalities reported in time perception in autism are present, or how these possible atypicalities in the different levels are related to the atypicalities that define the autistic spectrum. The aim of Chapter 2 is to understand what we really know about time perception in autism, what areas of study are more consistent, and where are the bigger gaps of knowledge that need to be addressed. So, the second chapter of this thesis presents a systematic review of time perception studies in autism, and the main methods used in those studies. This is the first time that the literature of time perception in autism is systematically reviewed.

Since autistic traits have been shown to be normally distributed in the general population (Constantino and Todd, 2003), if autism is characterised by atypical perception of duration, individuals from the general population with autistic traits at different degrees should show differences in how they perceive a given duration. The second aim of this thesis is to know whether the degree of presence of autistic traits is related to the temporal judgements the individuals make. This is addressed in Chapter 4 by an online study involving two experiments of interval timing in the general population.

Finally, a characterization of time perception processes in any atypical condition should assess that population and compare it with matched control participants. Taking into account the conclusions from the systematic review, it was clear that to characterise time perception in autism it was needed to conduct an assessment of the different levels of complexity of time perception behaviours. So, Chapter 5 presents 3 experiments to characterise time perception abilities from the sensorial level to more ecological higher-level time processing tasks, in order to show whether time perception is in fact atypical in autism and if it is, what type of time perception behaviours are affected.

2. Chapter 2: Time perception and Autistic Spectrum Condition: A Systematic Review

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Acknowledgements: MC was supported by a Presidential Doctoral Scholar (PDS) Award of University of Manchester, Manchester, UK and DP supported by was supported by the Economic and Social Research Council [Grant Number ES/P007732/1].

Conflict of interest: The authors have no conflicts of interest to declare.

2.1.Lay Summary

This systematic review examines the different types of timing and time perception behaviour that have been investigated in autism. Overall, there are a number of studies that show differences between autistic and non-autistic individuals, but some studies do not find such differences. Group differences are more consistent across studies using complex tasks rather than simpler more fundamental timing tasks. We suggest that experiments across a range of timing tasks would be fruitful to address gaps in our knowledge.

2.2. Abstract

Problems with timing and time perception have been suggested as key characteristics of Autism Spectrum Condition (ASC). Studies and personal accounts from clinicians, parents, caregivers and self-reports from autistic people themselves often refer to problems with time. Although a number of empirical studies have examined aspects relating to time in autistic individuals, there remains no clear consensus on whether or how timing mechanisms may be affected in autism. A key reason for this lack of clarity is the wide range of timing processes that exist and subsequently the wide range of methodologies, research paradigms and samples that time- based studies have used with autism populations (Allman and Falter, 2015; Jones et al. 2017). In order to summarise and organise the available literature on this issue, a systematic review was conducted. Five electronic databases were consulted. From an initial 597 records (after duplicates were removed), 45 papers were selected and reviewed. The studies are reviewed within different sections based on the different types of timing ability that have been explored in the neurotypical (NT) population: time sensitivity, interval timing and higher-order time perception. Within each section cognitive models, methodologies, possible clinical implications and research results are discussed. The results show different consistency across studies between the three types of timing ability. The highest consistency of results showing atypical time perception abilities is found in higher-level time perception studies. It remains unclear if autism is characterised by a fundamental time perception impairment. Suggestions for future research are discussed.

Key words: Timing, time perception, autism, systematic review, temporal order judgements, temporal sensitivity, prospective timing, scalar expectancy theory

2.3.Background

Autism Spectrum Condition (ASC, termed autism in this article) is a neurodevelopmental condition characterized by deficits in social communication and interaction, as well as repetitive behaviour and restricted interests (DSM-V; American Psychiatric Association [APA], 2013). Additionally, autism is often accompanied by unusual sensory experiences affecting individual or multiple modalities (Simmons et al., 2009), and altered motor behaviour such as poor eye hand coordination and unstable balance (Gowen and Hamilton, 2013). It has been suggested that disorders in timing and/or time perception may be a key characteristic, or cause of, some of the behavioural and cognitive impairments in autism (Allman, DeLeon and Wearden, 2011; Allman and DeLeon, 2009). However, it remains unclear the exact type of timing that is affected in autism and the impact that altered timing may have on the atypicalities that characterise the condition. Additionally, different timing abilities are anchored in different cognitive processes, but the evidence from these different (although likely related) abilities is often taken as a unique process suggesting a generalised impairment in time perception. This represents a source of imprecision that needs to be addressed, since characterising an heterogeneous condition such as autism, requires very precise terminology, well defined cognitive mechanisms and strong methodologies in order to improve the reliability of findings. This review seeks to evaluate the current evidence of whether time perception impairments exist in autism, and if so, which types of timing and temporal processing are affected. This review will also discuss how such deficits could produce the behavioural or cognitive atypicalities seen in autism.

The terms and processes around time perception research (timing, time perception, temporal processing, etc.) are often used inconsistently, without consideration of the time scale under study, or the complexity in terms of the cognitive demands the tasks involve. Broadly speaking *timing* is the co-ordination of action or thought to respond to time critical events in the environment. This includes predicting when events will occur in time and the timing of behaviour to occur at an optimal moment. Time *perception* refers to more specific cognitive skills (although distinguishable between them), such as the perception of the duration of an event or stimuli, the temporal order of stimuli, and having a sense of how quickly or slowly time seems to be passing. Other higher order abstractions cover a more general understanding of the passage of time, one's location in it, events occurring in certain temporal orders, and that objects change as a function of time. These higher order concepts about time may well be sub-served by the more specific skills of time perception, although experimental evidence of this is scarce. Indeed, the relationships between the different types of timing are poorly understood even in neurotypicals (NT). This review presents the different models used in time perception research in autism, provides specific and clearly distinguishable definitions of time perception for each model defining them and providing the corresponding evidence from those studies.

Self-reports from autistic people, as well as reports from those who have regular contact with them (parents, teachers and clinicians), often include difficulties with a sense of time. For instance, from Donna Williams an individual with Asperger syndrome who wrote a book of her inside view: '*for me, a problem with sequencing is also about sense of time and the continuity (or lack of it) in my sense of personal history'* (Williams 1996, as cited in Boucher, 2001, p. 165) or a report by a clinician

Lorna Wing (as cited in Boucher, 2001, p.88), who highlights (among other things) *'The difficulties lie in comprehending the passage of time and linking it with ongoing activities…'* . Although these quotes illustrate that autistic individuals experience difficulties with timing and time perception, they cannot be interpreted as proof that autistic individuals have an atypical perception of duration. In fact, it remains unclear whether the difficulties such as those presented in the quotes, are 'simply' a higher order understanding of time as an organiser of events, or whether these problems are caused by a fundamental perceptual problem of representing durations (or both). Here, we conducted a systematic review of the evidence for both higher order and fundamental timing deficits in autism.

The review is structured around the different types of timing ability that have been explored in the neurotypical population (Figure 2.1). Time perception studies have used a wide range of procedures involving different cognitive process, such as attention, working memory, executive function etc. (e.g. working memory load is highly relevant in interval timing, but not as strong in time sensitivity). Hence, this review is structured in three levels of complexity according to the increasing cognitive load demanded by the tasks used in the studies: Time sensitivity, Interval Timing, and High-level temporal processing. Within each section we (1) define the type of timing in question and the proposed cognitive mechanisms (where they exist) (2) describe the possible functional significance in relation to autism, (3) outline the results of studies that have examined autistic performance for that particularly timing ability, (4) present the time ranges used in the tasks, and (5) identify any gaps in empirical findings.

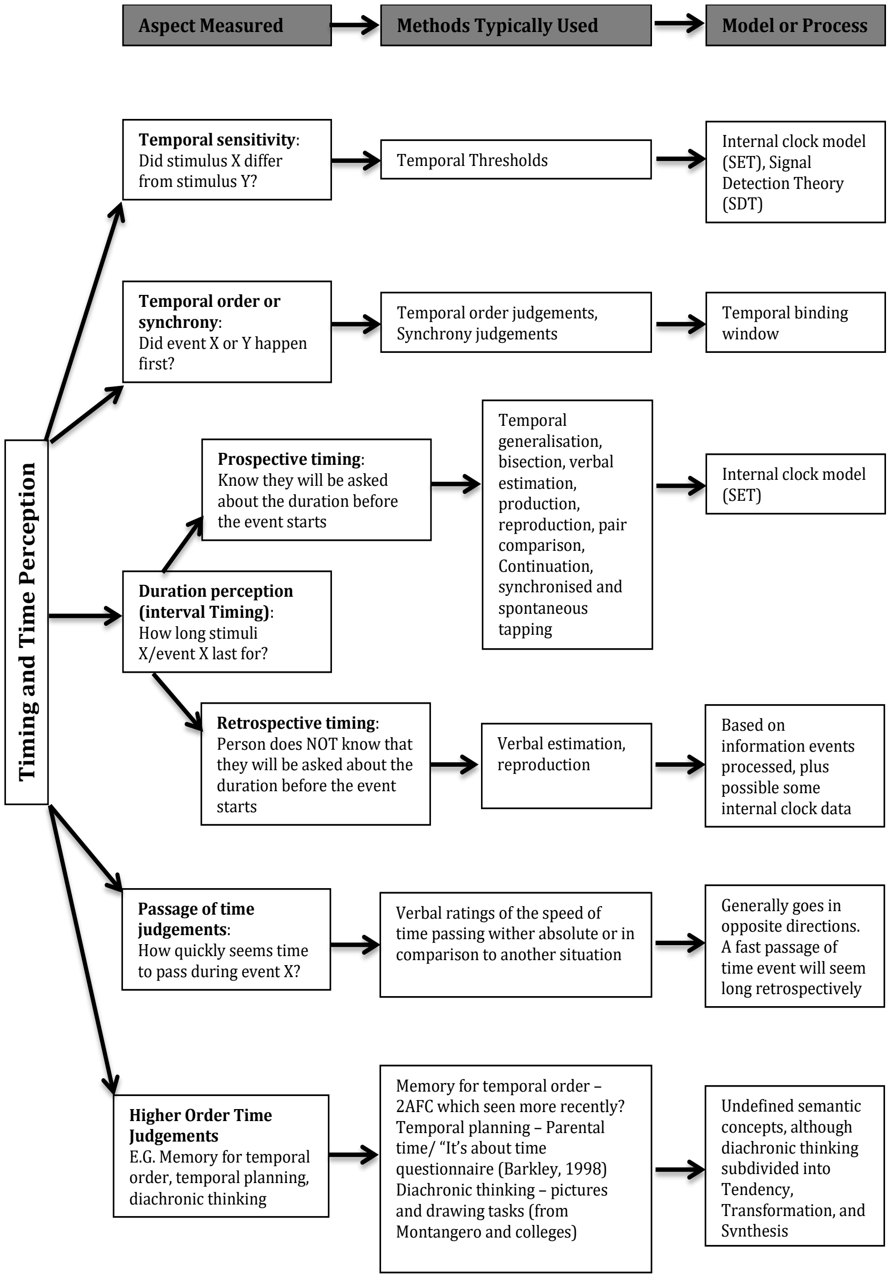

Figure 2. 1: Types and Measurements of Time perception

This review differs from existing reviews in the literature (Boucher, 2001; Allman and Meck, 2012; Allman and Falter, 2015; Stevenson, et al. 2015; Chan, Langer and Keiser, 2016) in that it is the first systematic review on time perception in autism. Also, we have classified a wide range of timing behaviours in a hierarchical level of complexity according to the cognitive models they are based on and tasks used. Thus, in addition to autism researchers this review should be useful to anyone approaching the timing field for the first time, and/or has an interest in exploring a particular condition (not just autism) and its relationship with timing and time perception.

2.4.Methods

A systematic search was carried out according with the guidance in the PRISMA statement (Moher et al. 2009). The literature search was conducted during March 2017, looking for research papers published in peer-reviewed journals without including any restriction in terms of year of publication. Web of Science (WOS), PubMed, Scopus, Wiley Online Library (WOL), and PsycINFO were consulted in the search using the term Autis* (so we picked up any derivation as autism, autistic, etc.) and its combination with *time perception* or *temporal order judgement,* or *time sensitivity,* or *temporal binding window* or *interval tim** or *prospective tim**. As exclusion criteria in the search the articles containing the terms schiz*or attentional deficit or hyperactivity were used. The reason for the exclusion criteria was that many articles about these conditions include autism in their conclusion and *autism* related terms in their abstracts or key words. Additionally, papers were included from suggestions obtained from research meetings.

Following the search, 596 papers were selected for abstract screening and another one was added at the end of the process (Jones et al. 2017 published online on 20th of April). Three of the authors of this review screened the titles and abstracts independently and selected 76 for full reading, using the following inclusion criteria: (1) article was a research article (no reviews or theoretical works); (2) including at least one direct measurement in time perception in autism using any of the following methodologies: qualitative, psychophysics, questionnaires, neuropsychological tests, physiological measures, neuroimaging or neurophysiology. In addition, the exclusion criteria were as follows: (1) research articles only about time or only about autism; (2) research articles about time perception and other conditions, disorders or pathologies including autism, but without presenting the autism data separated from the other conditions; and (4) articles about the use of the calendar in autism. The latter were excluded because they represent either a well-mastered algorithm for date calculation or highly specified mathematical abilities, rather than time perception. Finally, one more study was included following a peer-review suggestion.

From the 76 candidate papers, 31 were excluded. Twenty articles were excluded because they were not time perception research (but about other cognitive processes), or because the time perception data was not distinguishable from other cognitive processes. Five articles were excluded because they did not have an autism sample or the autism data were mixed with other conditions. A further two studies were excluded, because they covered circadian timing which is an area of research was not targeted in the current review (for readers interested in this area, interesting approaches can be found in Nicholas et al. 2008 and Hare, Jones and Evershed, 2006). Finally, four articles were discarded because they were not research articles (Figure 2.2).

The final 45 articles included in this review were separated by the type of timing ability investigated and are presented in the relevant section below. Also, because the perception of durations changes during development (Droit-Volet et al., 2007) and autism follows a heterogeneous developmental trajectory (Fountain et al., 2012), we have separated the research into adults and children.

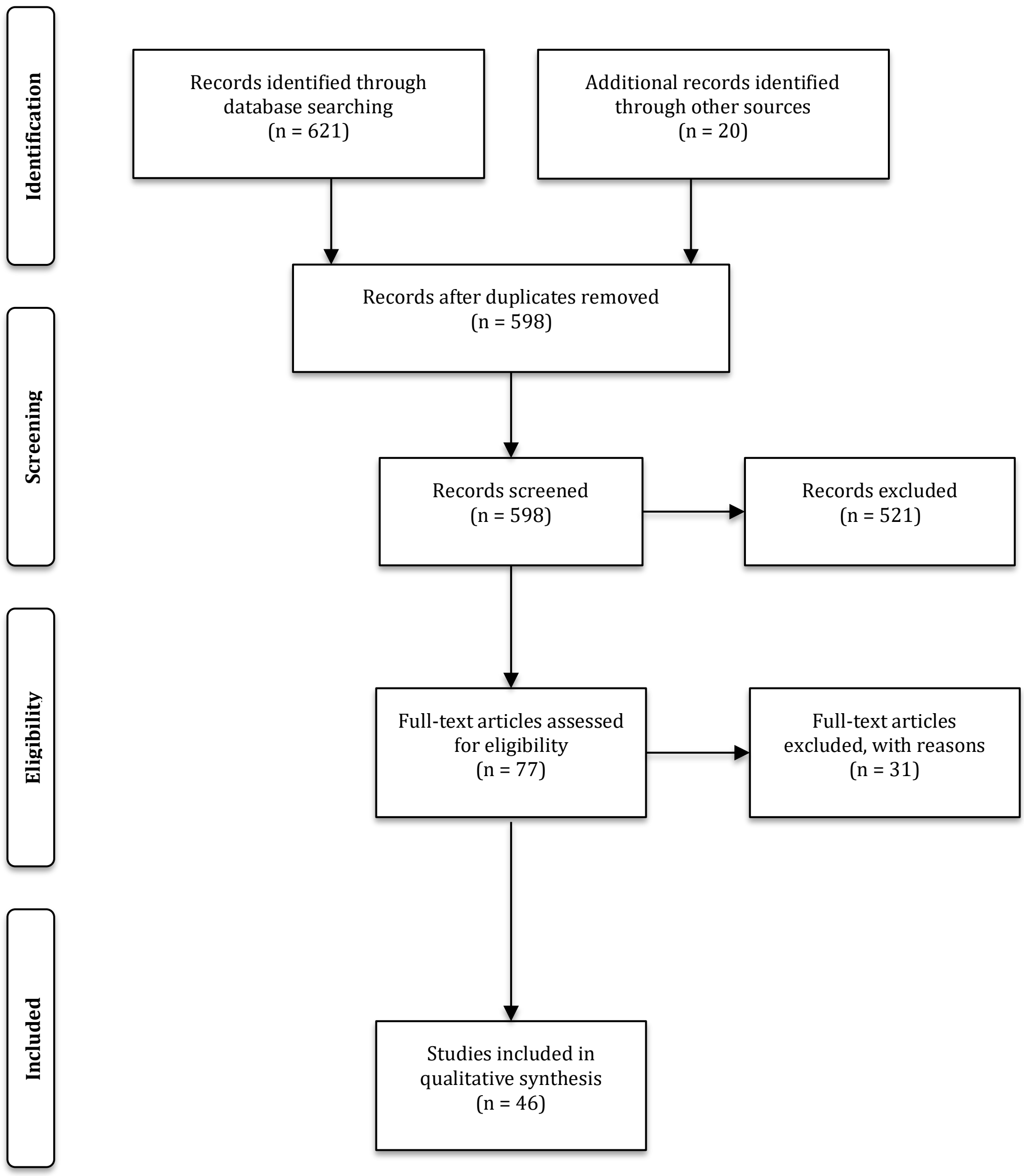

Figure 2. 2: Paper selection process flow diagram (modified from Moher et al. 2009)

Finally, we use identity first language throughout this article in line with the preferences of autistic people identified in Kenny et al. (2016).

2.5. Results

2.5.1. <u>Time sensitivity</u>

Temporal sensitivity measures a person's ability to respond to time or temporal stimuli in the environment. Unlike other perceptual processes, there is no information stream being transduced into an electrical-chemical signal by a sensory organ. Instead the temporal characteristics of external stimuli have to be extracted by mechanisms within the organism. Nonetheless we can still apply measurements of sensitivity that we would use in other sensory domains. Typically, time sensitivity research works in the millisecond range, and can be divided into temporal thresholds, temporal order/simultaneity judgements, and mismatch negativity studies using EEG.

Overall, 26 studies have researched time sensitivity, which we present according to the methodological approach.

2.5.1.1. Temporal Thresholds

Evidence of a pure timing impairment in autism would come from studies using a fundamental test of temporal discrimination, e.g. the measurement of thresholds for identifying when stimuli differ in temporal characteristics. A common method to research thresholds is a *staircase procedure*, where a standard time (of a fixed duration) is presented along with a comparison stimulus (variable durations). Then the participant identifies which of the two stimuli was longer. If the response is correct the next trial increases in difficulty (less difference between stimuli) and if the response is wrong, then the next trial decreases in difficulty. A typical temporal threshold procedure lasts for 50 trials and the threshold is estimated by averaging the last 20 trials (see Jones, Poliakoff and Wells, 2009 for a detailed example; and

Treutwein, 1995 and Leek, 2001 for a further discussion of adaptive methods). Time sensitivity research has shown differences in the ability to discriminate durations depending on the stimulus used in the task (see Rammsayer, 2010), which makes it difficult to compare the threshold values from one task with another. The most common stimuli used are filled durations (continuous tones), empty durations (delimited by a stimulus at the beginning and end; short beep – silence interval – short beep) or gap durations (a discontinuity; continuous tone – silence gap – continuous tone) (see Bathara et al. 2013, for an example of the latter).

Atypicalities with temporal thresholds may lead to a wide range of difficulties. If someone has very high thresholds (reduced temporal sensitivity), they would perceive two stimuli with different temporal characteristics as equal, while others would describe them as different. These differences may lead to perceive the world as overwhelming, since different stimuli may overlap or disjoint.

Five studies have examined temporal thresholds in autism using different variants of the methodology described above (Table 2.1). Amongst the 3 studies conducted in children, 2 of them found no differences between autistic and NT samples and 1 showed less time sensitivity in autistic adults. Mostofsky et al. (2000) found no differences between autistic children and matched controls in auditory thresholds using empty intervals and an abbreviated threshold procedure. Jones et al. (2009a) replicated the findings from Mostofky's study in a larger sample of children, but applying different methodology. Jones et al (2009a) used a *More Virulent* PEST, with a more complex stimulus than Mostofsky (two cartoons of a dinosaur making a "funny sound", as described by the authors) and provided feedback after each trial (correct or incorrect). In contrast, Bhatara et al. (2013) concluded that autistic children have impairments in auditory time sensitivity thresholds using a gap detection task, including feedback after each trial. The inconsistency in the findings between the 3 studies in autistic children could be due the different methodologies used.

The two studies in adults also used different threshold procedures and sensory modalities. Kargas et al. (2015) compared auditory temporal thresholds between autistic adults and matched controls, finding higher thresholds in autism and no correlations between thresholds and ADOS (Autism Diagnostic Observation Schedule) scores on the Stereotyped Behaviours and Restricted interests scales. The other study in autistic adults (Poole et al., 2015a) found no group differences examining tactile gap detection thresholds using a two interval procedure. Interestingly, a previous study using the same procedure (Poole et al., 2015b) found that higher tactile thresholds were associated with higher autistic traits in a NT sample.

Table 2. 1: Temporal Sensitivity measure by thresholds

		Sample		Modality	Tasks	Findings	Commentaries
		ASC	NT				
Mostofsky et al. (2000)	n	11	17	Auditory	Temporal thresholds: Empty intervals	Not significant larger thresholds in ASC	Presence of outliers Not a full threshold procedure
	Age	13.3 (6.8 – 17.8)	12.5 (8.3 – 16.7)				
	IQ	101 (81 – 132)	105 (80 – 133)				
Jones et al. (2009)	n	72	48	Auditory	Temporal thresholds: Filled intervals	No differences between groups in duration discrimination	A dinosaur is a more complex stimuli than the classic auditory paradigm. This can affect the participant attentional resources
	Age	15.6 (5.7)	15.6 (5.9)				
	IQ	87.79 (17.32)	89.33 (21.53)				
Bhatara et al. (2013)	n	12	15	Auditory	Gap detection thresholds: Gap detection	Higher gap detection thresholds in ASC (15ms) vs NT (5ms)	Small sample Lower verbal IQ in ASC (p <0.01)
	Age	10.42 (1.92)	12.83 (1.75)				
	VIQ	93(16)	111(13)				
	PIQ	99(16)	105(15)				
Kargas et al. (2015)	n	21	21	Auditory	Temporal thresholds	Higher thresholds and higher variability in ASC No correlation between SBRI† scores and duration discrimination in ASC	The authors warned that the SBRI scale of ADOS is not the best for measuring repetitive and restrictive behaviours.
	Age	30.3 (10.4)	29.5 (11.4)				
	IQ	109.5 (18.3)	115.9 (10.6)				
Poole et al. (2015)	n	18	18	Tactile	Temporal thresholds: Gap detection	No differences in tactile thresholds	
	Age	29.8 (8.1)	29.1 (7.2)				
	IQ	118.3 (9.9)	117.6 (13.4)				

† Stereotyped Behaviours and Restricted Interests

Overall, temporal thresholds have been researched using different sample characteristics, methodologies, sensory modalities and threshold calculation. In children, two studies show no differences and one shows differences between autistic and neurotypical samples. In adults, the results are also mixed with one study showing differences and one showing comparable performance. Some studies have included the presentation of feedback, which is a factor that could affect performance (by providing a learning cue, and/or prompting an emotional response). Future research should make efforts in replication studies using full thresholds procedures in each modality. Also, studying filled and unfilled auditory thresholds in autistic adults would be useful to see if the findings in children remain in older ages. No studies have been conducted in tactile thresholds in children and no studies in either children or adults have been conducted on visual temporal thresholds. The latter is important because visual and auditory thresholds differ (Jones, Poliakoff and Wells, 2009), so conclusions from one modality are not necessarily true for the other.

2.5.1.2. Temporal Order Judgements, Temporal Synchrony and Temporal Binding Window.

Another dimension of time sensitivity is discriminating whether events presented close in time are simultaneous, or preceded/succeeded by one another; that is Simultaneity Judgement (SJ) and Temporal Order Judgement (TOJ) (Figure 2.3). The measure of time sensitivity associated with this ability of separating stimuli in time is temporal acuity (TA) (Poole et al, 2016). Related to TA, is the concept of a Temporal Binding Window (TBW) where information from the different sensory modalities (e.g. in multisensory tasks) are integrated only if they occur in temporal proximity to each other (see Wallace and Stevenson, 2014 for a review in developmental disorders). A difficulty with TA may lead to problems with understanding which events in the world have been caused by our own action, termed a sense of agency (Gallagher 2000; Jeannerod, 2003). Differences in making cause-effect attributions could lead to superstitious thinking or self-referred logical thinking, commonly described in autism. Additionally, it may have implications in providing continuity to one's own experience and may be related to difficulties with prospective timing (see below).

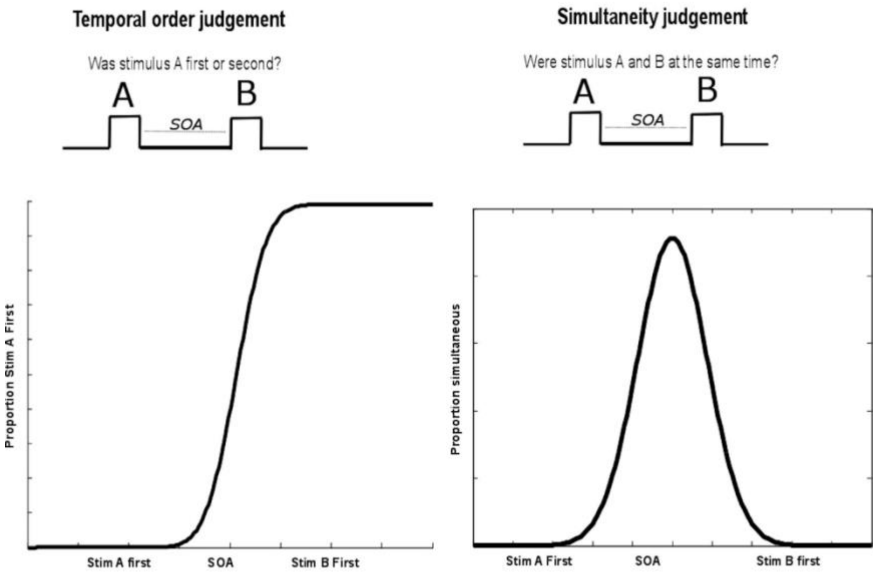

Figure 2. 3: Temporal order Judgement and Simultaneity Judgement: SJ and TOJ tasks involve detecting a temporal discrepancy, a TOJ involves additional processes such as identifying which of the two stimuli arrived first [Binder, 2015]. Two indices often used in the literature are the point of subjective simultaneity (PSS) and just noticeable difference (JND), which referred to the point where two stimuli are perceived as simultaneous and the smallest different between two stimuli to be judged as different respectively.

Fifteen studies have examined TOJ and SJ in different modalities, using a variety of methodologies. In 12 studies with autistic children, 7 used TOJ tasks and 5 used other tasks. Regarding the TOJ studies, 3 reported reduced TA in autistic children, one showed no differences between autistic children and matched controls and 3 studies showed mixed results (reduced temporal sensitivity in autistic children in some tasks/measures, but no differences in others). Wada et al (2015) demonstrated reduced temporal sensitivity in the tactile modality, whereas Puts et al. (2014), found no differences between autistic children and matched controls (Table 2.2).

Comparable performance between autistic and control groups in children has also been reported in the visual modality by Kwakye et al (2011), although the same study found reduced TA in the auditory modality in autistic children. Most bimodal research has focused on audio-visual interactions. De Boer-Schellckens et al. (2013a; 2013b) reported reduced temporal sensitivity in autistic children using a TOJ task in visual and audio-visual modalities respectively. Audio-visual interactions were also examined by Stevenson et al. (2014) and Noel et al. (2016) who reported no differences between autistic children and matched controls for simple stimuli (flash-beep) and complex stimuli (tool), but a wider TBW in autistic children for speech stimuli. In contrast, Foss-Feig et al. (2010) found a wider TBW in autism working with a different task (Flash-Beep illusion; see Shams et al. 2000 for a full explanation of the illusion).

Temporal integration of audio-visual stimuli has a relevant role in communication (e.g. in speech) and has been explored using tasks other than TOJ or SJ. Bebko et al. (2006) used a preferential looking paradigm, concluding that autistic children have an impaired ability to process asynchronous linguistic stimuli. Irwin et al. (2011) showed that autistic children rely more on auditory than visual information in audio-visual speech stimuli, and Grossman et al (2015) showed that autistic children dedicate less time looking at the mouth region of the face in speech stimuli. Using a different bimodal approach (visual-tactile), Greenfield et al. (2015) worked with the ‘rubber hand illusion’ showing no differences in sensitivity to asynchrony between autism and controls matched for mental age, but differences when compared to chronologically matched controls.

Table 2. 2: TOJ, SJ and TBW in ASC children and adolescents

		Sample					
		ASC	NT	Sensorial Modality	Tasks	Findings	Commentaries
De boer-Schellckens et al. (2013)	n Age IQ	16 19.3 (2.4) 106.2 (14.1)	16 19.3 (1.3) 106.6 (8.4)	Bi-modal (A-V) Handclap Speech Flash/beep	TOJ†	Lower time sensitivity in ASC group No differences between conditions	
De boer-Schellckens et al. 2013a	n Age IQ	35 18.8 (2.1) 103.2 (14.6)	40 18.8 (1.3) 107.9 (9.1)	Visual	TOJ	Lower time sensitivity in ASC group	
Kwakye et al (2011)	n Age IQ	35 12.21 (2.7) 102.9 (18.7)	27 11.73 (2.4) 109.5 (10.8)	Visual Auditory Bi-modal	TOJ	No differences in visual thresholds Less temporal sensitivity in auditory stimuli in ASC Larger TBW in ASC	
Puts et al (2014)	n Age IQ	27 10.7 (1.015) 103.14 (14.93)	54 10.08(1.28) 117.33 (12.24)	Tactile	TOJ	No differences between groups	Differences between groups in IQ.
Stevenson et al (2014)	n Age IQ	32 11.8 (3.2) 57.5 (8.4)	32 12.3(2.3) 53.7 (8)	Bi-modal Flash-Beep, Tool, syllable	TOJ SJ‡	No differences in Flash-beep and Tool Wider TBW in ASC for speech stimuli	ASC sample scored worst in verbal IQ
Wada et al (2015)	n Age IQ	10 11.8 (0.7) 100.7 (6.5)	10 11.7 (0.7) 101.6 (2.4)	Tactile	TOJ	Less temporal resolution in ASC No detriment of performance when hands-croosed	Small sample
Noel (2016)	n Age IQ	26 12.3 (3.05) 111.52 (14.73)	26 11.6 (3.79) 112.18 (7.56)	Bi-modal Flash-Beep, Tool, syllable	TOJ SJ	No differences in Flash-beep and Tool Wider TBW in ASC for speech stimuli	
Foss-Feig et al (2010)	n Age IQ	21 12.8 (2.61) 108.45 (18.7)	17 12.9 (2.2) 107.19 (9.3)	Bi-modal Flash-beep	Flash-Beep illusion	Wider TBW in ASC	
Irwin et al (2011)	n Age	13 9.08	13 9.16	Bi-modal (A-V)	Asynchrony	ASC sample performed similarly with mental age matched, but not with chronological age. No differences between groups	
Bebko, J. M., et al. (2006)	n Age	16 5.49 (0.51)	15 DD/16 NH 4.88 (0.72) DD/2.36 (0.68) NH	Bi-modal (A-V)	Preferential looking	ASC only showed preferential looking for asynchronous non-linguistic events.	
Grossman et al. (2015)	n Age IQ	30 11:10 (1:4) 104 (15.9)	30 12:5 (0.11) 109 (11.2)	Bi-modal (A-V)	Eye-tracking	Less gaze to in-synch condition in ASC Less gaze time to mouth area in ASC	

† Temporal Order Judgement ‡ Simultaneity Judgement A-V: Audio-Visual TOJ: Temporal Order Jusgement SJ: Simultaneity Jusgemente

TOJ studies in autistic adults have also produced mixed results. In Tommerdahl et al. (2008), the autistic sample exhibited higher tactile thresholds when the stimulus was applied to one hand, but comparable performance when the stimulus was applied to both hands. In contrast, Falter et al. (2012a) found superior visual TA in autism and a negative correlation between autistic symptoms and thresholds. A different approach by Poole et al. (2016) examined bimodal pairings (auditory – visual, auditory – tactile, and visual – tactile) in a TOJ task, finding no differences in any of the conditions (Table 2.3), however performance was correlated with sensory symptoms across the groups.

Table 2. 3: TOJ and SJ in high-functioning ASC adults without reported comorbidities and normal IQ

		Sample		Modality	Tasks	Findings	Commentaries
		ASC	NT				
Tommerdahl et al. 2008	n	10	20	Tactile	Unilateral SJ and TOJ	Worst temporal sensitivity in ASC	
	Age	26.1 (6.3)	24.2 (6.1)				
	IQ	102.8 (17.7)	115.6 (7.1)	Tactile	Bilateral TOJ	Comparable temporal sensitivity	No correlation with symptomatology done
Falter et al. 2012a	n	16	16	Visual	SJ	Better temporal sensitivity in ASC	
	Age	24.2 (7)	26.2 (7.4)				
	IQ	114 (13)	112 (9)			Negative correlation between temporal thresholds and autistic symptoms	
Poole et al. 2016	n	18	18	Bi-modal dyads (A-V, V-T, A-T) †	TOJ	No differences between groups in JND nor PSS for all the dyads	Differences reported in other studies in SOAs between 150 - 300ms were under-represented in the design
	Age	31 (8.43)	31.05 (8.71)				
	IQ	116.56 (9.7)	112.76 (7.56)				

[†] **A-V**: auditory – Visual; **A-T**: auditory – tactile; **V-T**: visual – tactile; TOJ: Temporal Order Judgement SJ: Simultaneity Judgement

There is a trend for TA and multisensory temporal integration for socially relevant stimuli to differ in autistic children and adults, but care must be taken when interpreting these differences as timing deficits as they may be confounded by reduced attention to social stimuli in autism (Dawson et al., 2004). A further issue is that many of the methodologies described in this section could be influenced by differences in response bias. For instance, on a SJ task autistic participants may be less conservative in the use of the 'simultaneous' response in conditions of relative uncertainty. This situation would lead to an increased frequency of simultaneous responses across a range of SOA and the apparent conclusion that temporal sensitivity was reduced in autism (or that the TBW is widened; see Yarrow, Jahn, Durant and Arnold, 2011 for a more detailed discussion of this issue).

2.5.1.3.Electroencephalography and time sensitivity in autism

Four studies have attempted to measure time sensitivity using electroencephalography (EEG). All these studies have worked with Event Related Potentials (ERPs), specifically with Mismatch Negativity (MMN), where bigger wave amplitudes are interpreted as better time sensitivity, in terms of higher discrimination (for a deeper understanding of ERP in time processing, see Macar and Vidal, 2004; Ng and Penney, 2014). In children, two studies (Lepisto et al., 2005, 2006) have shown diminished MMN amplitude, so implying reduced temporal sensitivity. In contrast, the studies in autistic adults (Kujala et al., 2007; Lepisto et al., 2007), showed enhanced discrimination abilities in autistic adults compared with matched controls, in frontal and central-line electrodes (Table 2.4).

Table 2. 4: Mismatch negativity studies in temporal sensitivity in ASC.

		Sample		Sensory Modality	Tasks	Findings	Commentaries
		ASC	NT				
Kujala et al. (2006)	n Age IQ	8 27 106	10 30 112	Auditory	EEG: MMN	Enhanced time sensitivity in ASC	Small sample
Lepisto et al. (2007)	n Age IQ	9 27 VIQ: 104; PIQ: 108	10 30 VIQ: 113; PIQ: 116	Auditory	EEG: MMN	Enhanced time sensitivity in ASC	Small sample
Lepisto et al (2006)	n Age IQ	10 8.11 VIQ: 108; PIQ: 112	10 8.1 VIQ: 107; PIQ: 114	Auditory	EEG: MMN	Diminished time sensitivity in ASC	Small sample
Lepisto et al. (2005)	n Age IQ	15 9.4 PIQ: 95	15 9.4 115	Auditory	EEG: MMN	Diminished time sensitivity in ASC	IQ differences between groups (although IQ did not correlate with any dependant variable)

EEG: Electroencephalography; MMN: Mismatch Negativity

2.5.1.4.Summary of Time Sensitivity studies.

Overall, several studies have researched time sensitivity in autism using different methodologies. In adults three studies showed enhanced time sensitivity, two studies show no differences between autistic and NT samples and two show reduced time sensitivity. Therefore, it is difficult to describe a clear trend for autistic adults in terms of their time sensitivity abilities. In children, eleven studies show reduced time sensitivity abilities in ASC, three show mixed results and three show no differences between groups. Taking into account that (a) there is more consistency across studies in children/adolescents than adults; (b) there are not enhanced abilities reported in children, but they are present in adults; and (c) there are more studies in children reporting impaired abilities, it can be hypothesised that there may be a differential developmental trajectory between autistic and NT individuals (although it should be noted that there are more than twice as many studies available for children compared to adults). Developmental studies of time sensitivity abilities are needed to explore this hypothesis.

2.5.2. Duration/Interval Timing

Interval timing is the perception of the duration of a stimulus or an event, allowing us to perceive how long a stimulus lasts for. It is crucial for our everyday interaction with the environment in predicting the timing of events. If impaired, one might become frustrated during waiting periods as they are not predictable, and delayed in reacting to events. Additionally, impairment in this area may impact on conversation turn-taking, and on social coordination, which requires a shared understanding of *when* an event will take place, therefore atypicalities in interval timing may be related to predictability issues in ASC. It has been suggested that these issues with interval timing may lead to repetitive behaviours as a possible strategy to parse time (Boucher, 2001; Allman, 2011). Also, one may have more difficulty anticipating the occurrence of daily events, or knowing how long one has been engaged in a particular activity, perhaps leading to the reported over-reliance on time keeping devices, or strict schedules of wake, sleep, eating, etc. that are reported in autism. Interval timing is also related to the ability to attribute cause and effect and our sense of agency.

2.5.2.1. Prospective Timing

Prospective timing involves the judgement of stimulus duration when the participant is aware that such a judgement will be required. For example, the participant listens to a tone, and makes some judgement about its duration, or compares its duration with a reference duration. As the participant is aware that this judgement will be required, they will be ready to start timing the stimulus as it commences. Prospective timing judgements are commonly thought to be underpinned by an internal clock system, based on Scalar Expectancy Theory (SET; Gibbon, 1977; Gibbon, Church and Meck, 1984). The system consists of three main stages, a clock stage (made up of a pacemaker, switch and accumulator), a memory stage (consisting of short term and reference long term memory), and lastly a comparison or decision stage where different durations can be compared to each other (Figure 2.4). Research in prospective time involves durations from the millisecond range to several seconds.

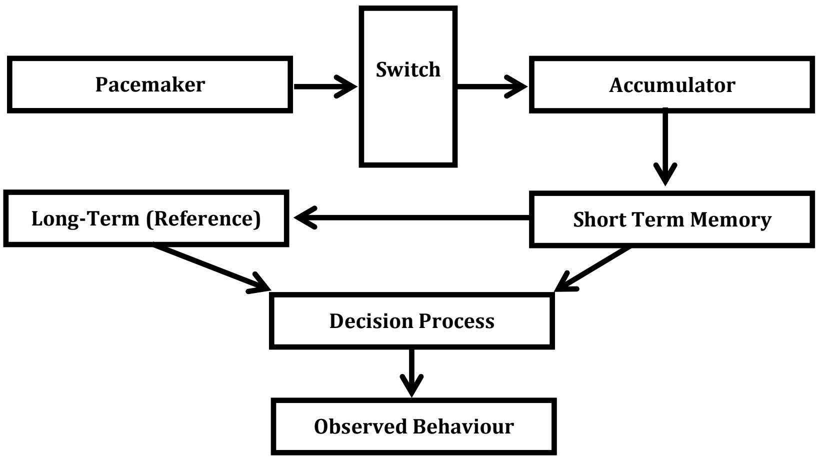

Figure 2. 4: When a duration is to be timed prospectively, the switch closes allowing pulses to flow from the pacemaker to the accumulator. At the end of the stimulus, the switch opens and pulses stop flowing. The amount of pulses or ticks accumulated is the subjective estimation of the stimulus duration. If this duration is important, or is to be used for future judgements it can then be stored in the reference or long-term memory. The comparator can make similarity judgements between the current duration (contents of the accumulator) and previously experience duration (contents of the reference memory).

There is a large body of evidence supporting pacemaker-accumulator clocks over other models (Wearden and Jones, 2007; Wearden, 2005; Wearden and Doherty, 1995). For example, human judgements of duration increase linearly with an increase in stimulus duration (implying a monotonic accumulator process), timing sensitivity is very accurate with difference thresholds as little as 10ms (dependant on the duration timed, as Weber's law , which states that the JND remains a constant fraction of the mean , holds for duration judgements) and humans can make ordinality judgements about different durations. An additional quality of the SET model is that its operation is mathematically defined, such that one can use computer modelling of timing data in order to identify which component can explain differences in performance (an example of such modelling for temporal bisection is shown in Box 2.1, other tasks such as generalization and magnitude estimation can also be modelled with SET).

Box 2.1: Computer modelling of temporal bisection.

The computer model of Temporal Bisection using the mathematics of Scalar Expectancy theory (from Droit-Volet and Wearden, 2001)

The model calculates two differences:

1) *D(s*,t)*

   This is the absolute difference between the current trial duration, t (which is assumed to be timed without error, or negligible relative variability) and s* which is a sample drawn on each trial from the (Gaussian) memory distribution of the short anchor.

2) *D(l*,t)*

   The absolute difference between t and l* which is a sample drawn from the memory distribution of the long anchor.

If $D(s^*,t) - D(l^*,t) < b$ (where b is the threshold value), then the model responds "long". If the difference is greater than *b* then the model responds "short" if $D(s^*,t) < D(l^*,t)$ and responds "long" if $D(s^*,t) > D(l^*,t)$. Essentially if the model cannot tell whether *t* is closer to the long or short anchor it responds "long". Variability in the system is controlled by three main variables, '*c*' which controls the coefficient of variation of the memories of the long and short anchors, K* which controls the mean of the memory distributions, (i.e. if the value of $K^*>1$ then the anchors are remembered systematically as being longer than they actually were, if $K^*<1$ then shorter) and '*b*' which controls the threshold.

<u>*Comparison methods*</u>: These tasks involve comparing a given stimulus with a previously given reference. The most common tasks are temporal bisection and temporal generalization. In temporal bisection, participants first learn to discriminate between two anchor durations, a long and a short duration. They are then given a range of durations that span (and include) these two anchors and are

asked whether each was more similar to the long or short anchor. Common indices are Bisection Point (BP), Difference Limen (DL) and Weber Ratio (WR). BP is the point in which a participant answer either Long or Short responses in same proportion. DL is the minimum difference between stimuli to be discriminated. WR measure of time sensitivity is based on the steepness of the curve (Figure 2.5). A key prediction of SET is that the WR should remain constant when different durations are timed, called the Scalar property, which can also be tested by looking for superimposition by plotting the psychophysical functions from two different anchor durations on the same relative scale as they should superimpose.

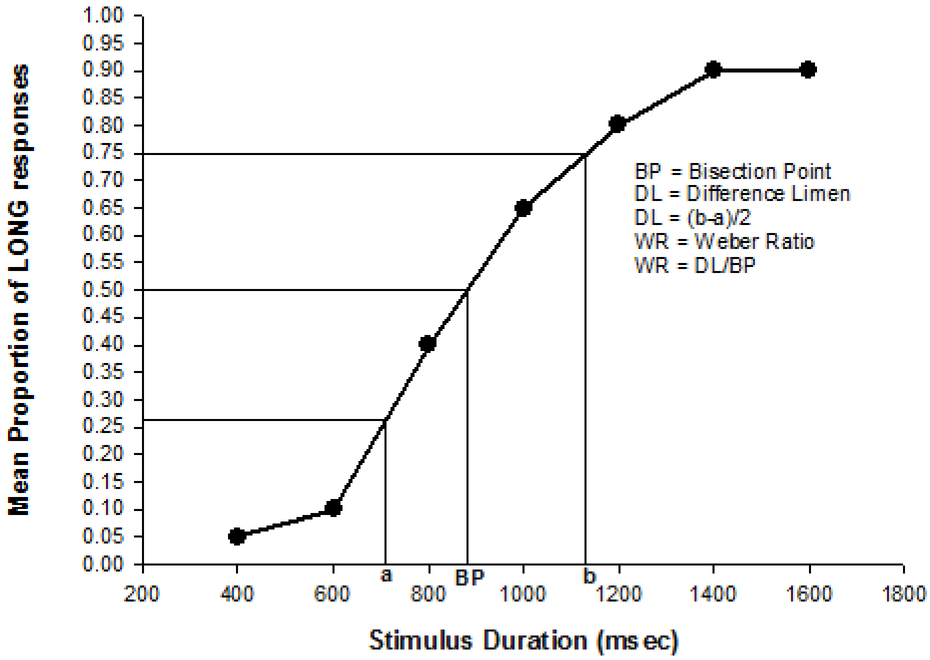

Figure 2. 5: Indexes from a Temporal Bisection Task**:** Psychophysical function in bisection tasks: Proportion of "Long" responses plotted against stimulus duration produces a typically sigmoidal psychophysical function, with "more similar to long" responses being at around zero at the shortest anchor and near 1 at the long anchor duration. The location of the bisection point (BP: 50% "long" responses) can characterize certain response biases, or memory effects either caused by individual differences or experimental manipulation. The BP is usually located at the arithmetic mean of the two anchors standards (in humans; Wearden, 1995). The difference limen (DL: temporal variability) can be calculated by taking half the differences between 25% and 75% "long" responses. The Weber ratio (WR, measure of temporal sensitivity) can be calculated by dividing the DL by the BP

In temporal generalization a 'Standard' duration (e.g. a 800 ms tone) is presented several times, then a number of comparison durations are presented (400ms, 500ms, …, 900ms etc. in a random order), and after each comparison presentation the participant is asked 'was that the Standard duration?' (Yes/No; see Figure 2.6). Data from generalization tasks can be tested for the scalar properties of interval timing.

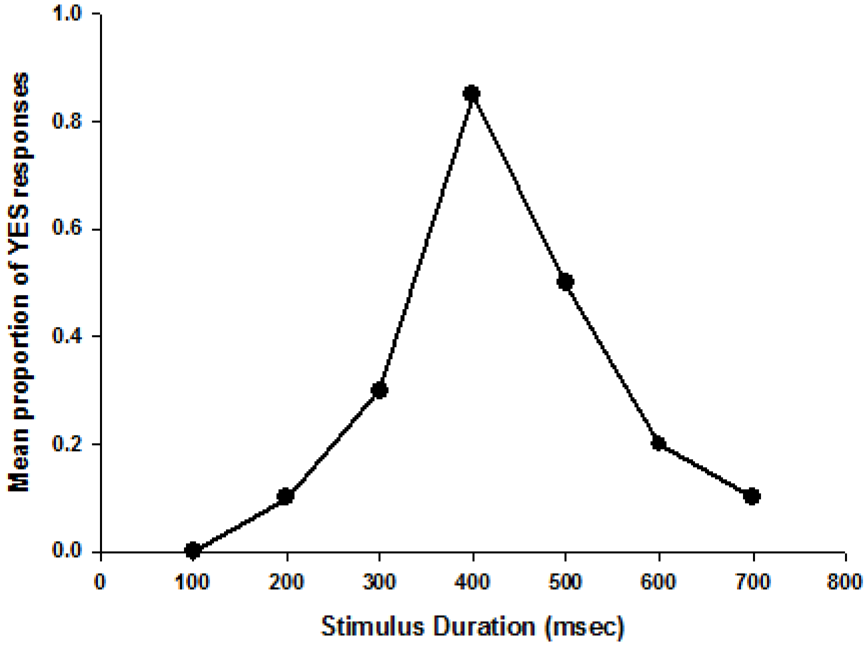

Figure 2. 6: Temporal generalization plot: Typical temporal generalization function plotted where the maximum number of "yes" responses typically occurs when the comparison is identical to the standard duration, and decreases as the difference between them increases. The steepness of this function gives a measure of temporal sensitivity, and because comparisons both longer and shorter than the Standard are presented, the function allows for the identification of distortion or asymmetry in responding. These functions are typically slightly asymmetrical in normal adults, with more YES responses to comparisons longer than the standard than for comparisons that are shorter; i.e., adult have a slight tendency to confuse durations that are longer than standard with the standard more than durations that are shorter (see Wearden [1992] for full discussion).

Five studies have worked with prospective comparison methods in autism, with 3 in children and 2 studies in adults. All the studies with autistic children used a temporal bisection task and one also used a temporal generalization task. Allman, DeLeon and Wearden (2011) used two versions of the temporal bisection procedure to examine autistic children (durations of 1 and 4 s, and 2 and 8 s). In both versions of the task, the autistic group's BP was located at a shorter duration than the controls. Although in the 1-4s range this effect appears to have been driven by abnormal performance of the controls, because they were higher than expected, and the autistic participants' BP was in the range reported by previous experiments with NTs. There were no group differences in WR for the 1 and 4s anchors task. In the second version, the autistic group had significantly higher WRs than the controls, indicating reduced sensitivity. Both NT and autistic groups demonstrated superimposition, although this was less strong for the autistic group. In the autism group, shorter BPs were associated with worse scores for language and communication (measured with ADOS) and working memory.

Allman et al. (2011) used computer modelling on the bisection data. The model is from Wearden (1991), and previously used to model data from typically developing children (Droit-Volet and Wearden, 2001; Box 1). This model fitted the data from the autism group and the controls well, for both anchor durations, with autistic individuals requiring a higher value of *c (which determines the memory variability)* to fit the data compared to the controls. In fact, the values obtained for the autism group were similar to those used to fit data from 5 year-olds NTs, whereas the values for the control group were similar to that used to fit data from 8-year olds (which are identical to adults). For the 1 and 4 s anchor experiment the values of K* (which determines the mean accuracy of the memory distribution of the anchors, see Box 1 (for discussion of K* and reference memory function see Jones and Wearden 2003, 2004) for both groups was similar to that of typically developing children in other studies. However, in the 2 and 8s anchor experiment the autistic group had a lower value of K*, suggesting that they systematically remembered the anchors as shorter than they actually were. This is a similar to that seen with 3 year-olds NTs (although on a generalization task: Droit-Volet, Clément and Wearden, 2001). Athough this is suggestive of developmental differences in autism, according to the authors themselves, one would need a much wider range of temporal tasks in order to characterise the amount and source of variance in the timing system.

Gil, et al. (2012) used a temporal bisection task with 4 different duration ranges, two long and two short, ranging from 0.5 – 16.63 seconds. They found no differences between groups in any of measure (BP, DL, WR). Consequently, Gil et al. (2012) concluded that autistic children have "the working raw material" for time perception and their day-to-day issues are probably due the integration of other cognitive processes (attention, memory, etc.) with temporal information to produce time judgements. However, as acknowledged by the authors, the results could have been influenced by a modification of the task to increase participants' sustained attention. A difference between Allman et al. (2011) and Gil et al. (2012) was that the modality of responses was different (key-press and verbal response respectively). Brodeur et al. (2014) reported reduced performance of 15 low-IQ autistic children compared to controls matched for mental age in temporal generalization and bisection tasks. Also, multisensory cartoons (image plus sound) were used to present the task, so the results may reflect issues with multisensory perception rather than time perception.

Researching autistic adults, Falter et al. (2012) used a temporal generalization task with visual, auditory and audiovisual stimuli. Autistic individuals showed a clearer adherence to the scalar property than the control group, as well as the same effect of perceiving auditory durations as subjectively longer than visual ones as the controls (a well characterised phenomenon in NTs, e.g. Goldstone and Lhamon, 1972, 1974; Jones, Poliakoff and Wells, 2009; Wearden, Todd and Jones, 2006). Signal detection analysis showed that the autistic group had reduced temporal discrimination compared to the controls, particularly for auditory stimuli. Lastly, the response criteria of the autism group was related to symptom strength in communication, the stronger the symptom strength the more conservative the response bias, i.e. the less likely they are to identify the comparison as the Standard (Falter et al., 2012). In contrast, Jones et al. (2017) found no differences between autistic adults and matched controls using a temporal bisection task and a set of stimuli of emotionally charged faces and wildlife images (Table 2.5). Although, the more complex nature of the stimuli used by Jones et al. (2017) have the benefit of being more ecological than simple beeps or flashes, they could increase the involvement of other cognitive processes, since it has been suggested that emotions affect our perception of duration, physiological arousal, attention and working memory (for a discussion see Lake, LaBar and Meck, 2016; Droit-Volet and Meck. 2007).

Table 2. 5: Prospective comparison tasks in ASC

		Sample		Task	Main conclusions	Commentaries
		ASC	NT			
Allman, M., DeLeon, I.G and Wearden, J.H. (2011)	n Age IQ	13 10.3 92.31	12 10.3 109.8	Temporal Bisection	Bisection point in ASC shorter than NT in two anchors (1 – 4 and 2 – 8 seconds) No differences in WR in anchor 1 – 4 s. Higher WR in ASC in anchor 2 – 8 s.	Small sample. Weak characterization of the control group
Gil et al. (2012)	n Age IQ	12 13 94.37	12 13.21 101.45	Temporal Bisection	No differences in BP, DL or WR. Good adjustment to scalar timing properties in both groups	Small sample. Changes in the research paradigms were introduced to maintain participants' attention; however this effect was not tested.
Brodeur et al. (2014)	n Age	15 10.74 (3.93) CA 7.3 MA	15 6.46 (0.93) CA 6.46 MA	Temporal Generalization	No group main effect, but group by duration main effect was reached.	No computer modelling or signal detection theory applied in either task.
	n Age IQ	15 10.16 (3.93) CA 6.19 MA	15 6.61 (0.78) 6.22 MA	Temporal Bisection	Higher DL and BP in ASC No group main effect, but group by duration main effect was reached.	No p-values reported for DL, BP or WR comparisons.
Falter et al. (2012a)	n Age IQ	18 25.3 112	19 26.1 113	Temporal Generalization	Less temporal sensitivity in ASC. Higher consistency in the responses between different time intervals	
Jones et al. (2017)	n Age IQ	20 45;4 114.6	26 44 108.1	Temporal Bisection	No differences between groups in WR or BP	No computer modelling performed or signal detection theory

WR: Weber Ratio; BP: Bisection Point; DL: Difference Limen

<u>Estimation methods</u>: involve estimating a given duration and expressing it with some pre-defined behaviour (writing, verbalizing, pressing etc.). The most common tasks are verbal estimation (an answer in time physical units such as seconds or milliseconds), temporal reproduction (the participant recreates a given duration) and temporal production (the participant produces a duration from a given temporal target usually in second or milliseconds). Common indices in these tasks are accuracy (e.g. mean of the interval reproduce/verbally estimated/produce, divided

by the reference duration) and consistency (variability measure e.g. coefficient of variation). These measures allow comparison of performance between different references, overestimation and underestimation of durations.

Eight studies have researched prospective time by estimation methods in autism, with five of them studying autistic children. Szelag et al. (2004) compared 7 autistic and NT children across a range of durations from 1 – 5.5 seconds in visual and auditory modalities. Performance was worse in the autistic group who reproduced all the durations at around 3-3.5 s, so they did not adjust to scalar timing. Importantly, the groups were not well matched on IQ, so differences could arise from IQ differences rather than autism diagnosis.

Wallace and Happé (2008) conducted a study using a stopwatch in tasks of verbal estimation, production and reproduction in 25 autistic adolescents and matched controls, using durations from 2 – 45 seconds. No differences were found between groups in the three tasks, but there was a trend for better performance in the time reproduction task in the autistic group. However, the authors acknowledge that the recruitment of savants could have been a factor affecting their results. In contrast, Maister and Plaisted-Grant (2011) performed two time reproduction experiments in which participants pressed a key (instead of the researcher using a stopwatch as in Wallace and Happé, 2008), - In their first experiment, they found impairments in short durations under 2 seconds, and for the longest duration of the task (45 s). In the second experiment, they only found differences in the extreme durations they used (0.5 and 45 s). They also investigated the relationships between time reproduction and memory abilities. Short term memory was correlated with the error scores for short durations between 1 and 10 seconds in both groups, but no statistical significance was found with the shortest duration of 0.5 seconds. For long durations (>30 seconds), a significant correlation was found between long term memory and time reproduction only in the NT group.

Brenner et al. (2015) compared the performance in a time reproduction task between autistic and matched control children and adolescents. Using times ranging from 4-20 seconds, the authors observed poorer performance in the autistic group in accuracy and consistency, with the first index being associated with age, and the second with working memory. Recently, Karaminis et al. (2016) found that autistic children performed significantly worse than the matched control group in time reproduction in terms of accuracy, but not consistency. Additionally, they worked with a discrimination task showing higher thresholds in the autistic group (similar to a younger group 6-7 years old). The authors hypothesise that this could be explained by reduced integration of a central tendency prior (bias to the mean duration of previous stimuli), more than due a developmental delay (see Pellicano and Burr, 2012, and commentaries for further discussion). To assess the latter, the authors employed Bayesian modelling, finding less influence of prior knowledge in autism in comparison with NT. Finally, all groups of children showed underproduction of the duration in the time reproduction task, a phenomenon that did not appear in the adult group, but that has been described for children in previous studies (McCormack et al. 1999).

In adults, findings using estimation methods are mixed. Gowen and Miall (2005) used a blend of reproduction and classical synchronised and continuation tapping, finding that the autism group had greater absolute error and greater stimulus asynchrony on the synchronization task, but without differences in the coefficient of variation. Hypothetical differences in the clock speed would show only a difference (if any at all) between the two groups on the continuation task (continuing to tap without a beat) and not on the synchronisation task (tapping in time to a beat). If two groups differed in internal clock speed by a factor of two, then they could both still show identical synchronisation, with one group simply timing their tapping after *n* ticks and the other after *2n* ticks of the internal clock. In the continuation task, one might expect to see some difference as they are no longer being presented with an external time marker (the beep) to which to calibrate their responses. It is possible that these findings indicate greater impairments in motor rather than clock variance, but this would need a full Wing-Kristofferson (1973) type design to tease apart these alternatives (see Wearden and Jones, 2013 for a detailed explanation of this issue). To date, no study has separated perceptual clock timing from motor timing in autism. Given the frequent occurrence of movement difficulties in autism (Gowen and Hamilton, 2013), this is an important issue to investigate.

Using a time reproduction task, Martin, Poirier and Bowler (2010) found worse performance in the autistic group in measures of absolute difference, mean judgement ratio and coefficient of variation. Finally, Sperduti (2014) using a verbal estimation task reported comparable performance between autism and NT groups in terms of accuracy.

Table 2. 6: Prospective estimation task in ASC

		Sample		Task	Main conclusions	Commentaries
		ASC	NT			
Szelag et al. (2004)	n Age IQ	7 12.6 82 - 102	7 Matched 95 - 145	Time reproduction	ASC group performed worst in the time reproduction task	Small sample Different IQ test in each group Trend to differences in IQ
Gowen and Miall (2005)	n Age IQ	12 24.2 114	12 24.2 114	Continuation and synchronization tapping	No differences in Coef. of variation. ASC group showed greater absolute error and greater stimulus asynchrony on synchronization task.	Small sample
Wallace and Happé (2008)	n Age IQ	25 14.1 96.36	25 13.84 100.08	Verbal estimation, production and reproduction	No statistical differences in time reproduction, time production and time estimation	Recruitment of savants and a modification in the experimental paradigm could have been a factor affecting the results
Martin, Poirier and Bowler (2010)	n Age IQ	20 35 106	20 35 108	Time reproduction	ASD group worse on measures of; Absolute Difference, Mean Judgement Ratio and Mean Coefficient of Variation	No control of chronometric counting
Maister and Plaisted (2011)	n Age IQ	21 11.3 105.6	21 10.7 115.8	Time reproduction	Differences in short (0.5 s.) and long durations (45 s.) Short term memory was correlated with the error scores in short durations between 1 and 10 s	No data about over or underestimation. Trend to differences in IQ
Brenner et al. (2015)	n Age IQ	27 12.68 101.31	25 13.41 106.96	Time reproduction	Poorer accuracy and consistency in ASC group. Accuracy was found associated with age and consistency with working memory	
Karaminis et al. (2016)	n Age IQ	n = 23 Age: 12 IQ: 100.03	n = 78 (6 – 32 years old)	Time reproduction and discrimination	ASC group performed similar to younger children (6-7 years old) Less use of priors in ASC ASC children less accurate, but equally precise (consistent) in time reproduction task	Child friendly paradigm. The authors suggest using the traditional paradigms in order to avoid this possible interference.
Sperduti, M., et al. (2014).	n Age IQ	15 33.53 109.38	17 33.06 105	Verbal Estimation	Comparable reproduction error between groups	

2.5.2.2. *Summary of Prospective timing in Autism*

As with temporal sensitivity, studies on prospective time involve a wide variety of methodologies and sample characteristics. Comparison methods have produced mixed results with indices showing differences between groups in some durations but not in others, and in all the studies there is at least one index showing no differences between groups. In children, two studies (out of three) show differences between groups in some indices, and in adults one study show differences and one report comparable performance. Altogether, the evidence from studies using comparison methods of prospective timing do not allow us to conclude a generalise impairment in these abilities in autism. Although, vulnerability in the abilities required by these tasks cannot be ruled out and in fact three out of five studies show differences between groups. More research is needed to identify which processes do or do not differ from general population.

In estimation methods, the findings are also mixed although they tend to show differences between groups. In children four out of five studies show worse performance in autism, while in adults two out of three studies show at least one measure of reduced performance in autism. Also, in general the autistic group tend to show greater variability in their responses. It is important to note that many of the estimation methods studies make use of reproduction paradigms involving motor abilities that are absent in other paradigms, adding an additional variable that could be affecting the performance of the autistic sample in ways that is not measured or controlled.

Surprisingly, no studies have used comparison and estimation methods in the same sample, which would allow to establish relationships between the indices from the computer models in comparison methods, and the estimation methods indicators, which have the comparative leverage of being a perception in the same physical units the stimulus is defined. It is worth noting that the studies which have investigated effects of memory on timing performance (extracted from computer modelling or correlated with other tasks) suggest that memory impacts on prospective timing judgements in autism.

2.5.3. Higher Level Temporal Processing

This section discusses the capacity to think about time as an abstract concept, where events take place within it, and the ability to be aware of one place in time and plan for events in the future. These set of processes are related to other complex cognitive processes such as episodic memory (e.g. when assigning temporal order to memories) and executive function (e.g. planning future actions, or managing information to do things '*on time*') , and the tasks involve perception of durations, meaning and management of time in a range of minutes, hours, days or even years. Possible impairment associated with these abilities may lead to difficulties in giving continuity to one's own experience. For instance, not knowing the temporal order of previous events would have consequences in assigning cause-effect relationships between your past experiences and your current behaviour, and in your ability for planning future events using current and past information.

2.5.3.1.Time-based prospective memory

Time-based prospective memory (TBPM) is the ability of remembering to behave in a previously defined moment, a previously planned action (Williams et al. 2013). It has been hypothesised that autistic people have problems with this ability because of the high demands on executive function these tasks require. Five studies have researched TBPM in autism differentiating between time-based and event-based prospective memory (EBPM: remembering to behave in a specific manner when a previously defined cue is present in the environment).

Altgassen et al. (2012) compared 25 NT and 25 autistic adults' performance in the *Dresden Breakfast task* measuring TBPM and EBPM. Participants were asked to prepare breakfast for hypothetical visitors, so they needed to remember to take out the tea-bag after three minutes in the cup or to put the butter in the table 6 minutes prior the arrival of the guests. If participants did these tasks with +-60 second, they were scored as correct. Also they recorded how many times they looked at the clock when performing the task. Autistic participants performed worse in both TBPM and EBPM tasks. This study also found a relationship between executive function and TBPM (but not with EBPM). Kretschmer et al. (2014) also found worse performance in the autistic group, but using a different task (virtual week prospective memory task). The third study in autistic adults (Williams et al. 2014) also reported diminished TBPM in autism, but comparable performance in EBPM. In the studies with children, Williams et al. (2013) and Henry et al. (2014) found impaired abilities of TBPM in autism but conserved EBPM, although different tasks were used in each study (table 2.7).

TBPM findings are highly consistent across studies with all the studies showing differences between groups. A limitation common to all of these studies is that these tasks assessed the ability to follow an instruction at designated times, but because the participants had the option of looking at a clock, it is very difficult to know if the differences between participant groups are due to a pure time-based prospective memory issue, or if they respond to problems with executive function (e.g. monitoring). Future research should measure prospective time tasks to assess the possible effects of basic timing abilities on TBPM.

Table 2. 7: Higher-level time processing

		Sample		Higher-level time processing ability	Tasks	Findings	Commentaries
		ASC	NT				
Altgassen et al. (2012)	n	25	25	Time based and event based prospective memory	Dresden Breakfast task	Autistic group performed worse in both tasks Relationship between TB-PM and executive function	Clock was available to be checked
	Age	21.8(6.68)	21.8(6.06)				
	IQ	>85	--				
Kretschmer et al. (2014)	n	27	27	Time based and event based prospective memory	Virtual week prospective memory task	Autistic group performed worse in both tasks	Clock was available to be checked
	Age	35.63 (10.12)	39.85 (8.50)				
	IQ Raven	40.81	40.58				
Williams et al. (2014)	n	17	17	Time based and event based prospective memory	Word recognition task	Autistic group performed worse in TB-PM, but comparable in theEB-PM	Clock was available to be checked
	Age	31.06(9.64)	31.92(14.17)				
	IQ	114.06(15.16)	117.71(13.05)				
Williams et al. (2013)	n	21	21	Time based and event based prospective memory	2D computer-based driving game	Autistic group performed worse in TB-PM, but comparable in theEB-PM	Clock was available to be checked
	Age	10.60 (2.01)	10.59 (1.31)				
	VIQ	103.57 (17.88)	106.48 (14.01)				
	PIQ	110.19 (16.35)	107.48 (13.23)				
Henry et al. (2014)	n	30	30	Time based and event based prospective memory	Virtual week prospective memory task	Autistic group performed worse in TB-PM, but comparable in the EB-PM	Clock was available to be checked
	Age	10.1(1.47)	10.0(1.46)				
	IQ	112.93(16.71)	115.3(14.69)				
Bennetto, Pennington and Rogers (1996)	n	19	19	Memory for temporal order	An adaptation of the Corsi Memory task.	Autistic group perform worse for words and pictures	Comparison group was a mix of individuals with non-autistic learning disabilities
	Age	15.95(3.3)	15.23(2.6)				
	IQ	88.89 (11.1)	91.74				
Gaigg, Bowler and Gardiner (2013)	n	22	22	Memory for temporal order	Historic figures task	Autistic group showed difficulties in the order of episodic, but not semantic memory	Differences in Executive function and attention.
	Age	37.6(13.4)	40.5(10.8)				
	IQ	103.4(13.4)	107(16.4)				
Boucher et al. (2007)	n	23	23	Diachronic thinking	Tendency, Transformation, Synthesis	Autistic group was impaired in the three measures	
	Age	12.6(2..3)	12.3(2.25)				
	IQ (raven)	29(5.3)	27(5.4)				
	n	15	15	Diachronic thinking	Tendency, Transformation, Synthesis	Autistic group was impaired in the three measures	
	Age	14.3(1.83)	14.6(1.5)				
	IQ (raven)	26.4(4.5)	23.7(6.3)				

TBPM: Time-Based Prospective Memory; EBPM: Event-Based Prospective Memory

2.5.3.2. Temporal Planning, Memory for Temporal Order and Diachronic Thinking

Three other studies have approached high level temporal processing issues in autism. In Allman et al. (2011) discussed earlier, the parents of the participants were given a 'Parental time Questionnaire', modified slightly from the "It's About Time" questionnaire (Barkley, 1998). The test contains such questions as: 'How often does your child ask questions about their past?', 'How often does your child refer to a watch or clock in planning how much time he or she has left to do something?', 'How often does your child talk about or seem to think about what he/she will be doing tomorrow?'. Overall the mean score for the autistic participants was significantly lower than the comparison group.

Bennetto, Pennington and Rogers (1996), investigated autistic children and adolescents and compared them with a clinical comparison group with non-autistic learning disorders using a task of *memory for temporal order*, which is the ability to give the correct temporal order to events already located in either long or short term memory (differing from TOJs which are an immediate perceptual judgment). The autism group performed worse than controls for both pictures and words suggesting they were less able to represent temporal order in memory. In adults, Gaigg, Bowler and Gardiner (2013) studied the temporal order allocated to well known historical figures, finding difficulties in the order of episodic memory, but not in semantic memory (a class of memory that does not imply a temporal dimension). The authors acknowledge that the differences could be due to executive function and attentional issues, although that does not discard the presence of episodic memory difficulties.

Finally, Boucher et al. (2007) researched *diachronic thinking*, defined as 'the propensity and capacity to think about events spreading across time'. The authors took the work from Montangero and colleagues who had investigated the development of diachronic thinking in NT children (Montangero, Pons and Scheidegger, 1996; Pons and Montangero, 1999). They had identified three components of this type of thinking: *Tendency* ('the tendency to think 'backwards' and 'forwards' across time'), *Transformation* (understanding that qualitative and quantitative changes can take place over time) and *Synthesis* (the ability to conceive of several distinct events forming parts of an overall whole). In two different studies, one in children and one in adolescents, Boucher et al (2007) reported worse performance in autism compared to controls.

2.5.3.3.Summary of Higher Level Temporal Processing

The evidence in higher order timing consistently shows impaired abilities in autism (all the studies point into the same direction), in comparison to low order timing as shown in time sensitivity and interval timing (mixed findings). However, replication is needed since the number of studies is small for some of these abilities, and due to the tasks used in these studies it is very difficult to disentangle the processes related to time perception from other cognitive abilities like memory and executive function. Future studies should attempt to address this issue and may use strategies such as those used in interval timing; computer modelling (Allman, DeLeon, Wearden, 2011), or relating timing performance with memory abilities (Maister and Plaisted-Grant, 2011). It would be useful to measure these processes in conjunction with measurements on the more fundamental/lower order timing tasks to see how (or if) they map on to each other and/or on to other traits of autism.

2.6.Conclusions

Autism involves a complex profile of cognitive differences across attention (Keehn, Lincoln, Muller and Townsend, 2011; Keehn, Muller and Townsend, 2013), social cognition (Dawson et al 2004) and working memory (Kercood et al, 2014). This review aimed to provide more clarity regarding whether the time perception difficulties often reported in are due to impairment in basic timing mechanisms, or are consequences of other cognitive impairments in autism. To this end, we systematically reviewed the scientific literature involving explicit measurements of time perception abilities in autistic population. The selected articles were categorised in three main clusters about the time perception ability: temporal sensitivity, interval timing, and high level temporal processing. It remains unclear as to whether atypical timing is characteristic of autism, at least in terms of differences in the function of the internal clock. Findings from the literature revealed inconsistent findings, with a trend of finding differences in some tasks, but not in others. Divergent performance appears to be more commonly observed where tasks place demands on other, non-timing cognitive processes and are less consistent in studies of fundamental or 'pure' time perception abilities (tasks with less involvement of other cognitive resources). For example, in the studies of temporal thresholds, 3 out of 5 studies showed comparable performance between groups. In contrast, TBPM (i.e. a task that involve more complex cognitive demands), all the studies show evidence of impaired abilities in autism. So, while autistic people may or may not have problems distinguishing the durations of two stimuli such as two beeps (or some may have issues while other autistic individuals not), the evidence shows that they may show issues with instructions such as 'we will lunch in *five* minutes' (a TBPM task). A previous review by Allman and Falter

(2015) proposed a similar explanation, but circumscribed to the supra-second range as time judgement would get “worse as duration increases into the bounds of secondary executive function (working and episodic memory, sustained attention)”(pp.52).

We have argued that the differential consistency between the three levels could be explained by the differential cognitive load their tasks demand. Time sensitivity is mainly determined by a perceptual mechanism (depending on the sensory modality) and attention (except in MMN in EEG studies), with low participation of other processes such as working memory and no involvement of long-term reference memory or executive function. Prospective interval timing tasks as explained by SET model have demands of attention, working and long-term reference memory, and decision making. Time-based prospective memory, where all studies showed differences between groups, adds a strong demand of executive function, since participants need to take decisions while multitasking, plan and adhere to a plan, inhibit behaviour, and switch their attention between different stimuli. So, it is possible that the differences in consistency between studies are anchored in those non-timing cognitive processes, and not in an atypical ‘pure’ time perception mechanism.

The studies in temporal sensitivity reveal informative trends about how autistic people distinguish between the temporal characteristics of stimuli in the environment. Temporal thresholds findings are mixed in children and adults, which could be explained by the different methodologies used in these five studies. This lack of consistency in the findings between studies should encourage replication studies, and make us question how robust the measurements that we are applying are, or how comparable the different methodologies to estimate thresholds are.

Studies in TOJ, SJ and temporal integration of multisensory information, (although showing mixed results) tend to more consistently report atypicalities in autism. The studies reporting atypicalities in temporal integration of audio-visual stimuli in speech (Bebko et al., 2006; Irwin et al. 2011; Grossman et al., 2015; Stevenson et al., 2014; Noel et al., 2016) are consistent and might be related to the difficulties in language development, a common reported comorbidity in autism. Interestingly, language and communication symptomatology correlated with atypical performance in two studies of interval timing (Allman et al, 2011; Falter et al., 2012).

As shown by the EEG studies, atypicalities in autism show impaired abilities in childhood, but enhanced abilities in adulthood (findings from EEG studies are consistent in this trend), suggesting a possible differential developmental trajectory for duration, since other auditory features as pitch have been described as enhanced in both children and adults (Kujala et al. 2007). Taking into account that learning processes are likely to mediate those developmental trajectories, and that cross-modal temporal processes improve with practice and training in the general population (Powers, Hillock and Wallace, 2009), future research could investigate how trainable these abilities are, and the possible impact of a program to train time on the social and non-social atypicalities that characterise autism.

In the interval time studies, two studies concluded that autistic children performed similarly to younger neurotypical children (Allman, DeLeon, Wearden, 2011; Karaminis et al., 2016), which is consistent with the findings of temporal sensitivity suggesting a differential developmental trajectory in autism. One factor that may affect this differential developmental trajectory is working memory, a skill that has been shown to have strong age-related components (Bayliss et al. 2005) and that is in the core of SET model (thus affecting performance in interval timing tasks). Also, working memory has shown an association with the performance of autistic individuals in interval timing tasks (as in Allman, DeLeon, Wearden, 2011; Brenner et al., 2015). Further research using computer modelling should involve a control task making judgements about another, non-time related stimulus dimension (for instance pitch; see Harrington et al, 1998) in order to provide stronger evidence regarding possible atypicalities in each SET model component. Indeed, atypicalities in integration rather than impairment in basic processes (as a pure perceptual issue could be) have been proposed in autism in other areas (for an example in sensory-motor integration, see Gowen and Hamilton,2012).

An area of interval timing where our systematic search showed no results was retrospective timing, (i.e. after the time limits of this systematic review there is one study including retrospective timing data. See Isaksson et al., 2018). Retrospective timing is the judgement made when the participant is asked an unexpected question about a duration. For example, if you were asked how long have you been reading this document, you did not know at the start of reading that you would be asked this, so you could not have started your clock mechanism. People are able to make such duration judgments with some accuracy, although considerably less than for prospective timing (Hicks, 1992). To date there is a paucity of retrospective timing studies even in NT populations, mainly due methodological problems as once participants have completed one trial then they are alerted that timing judgments are required, and any further judgements will be prospective. However, this would be a fruitful area of research in ASC.

Different aspects of higher level temporal processing have been researched, with consistent findings of atypicalities in autism. Tasks like "Dresden breakfast task" used in TBPM have an ecological validity, and future approaches could complement such measurements with fundamental timing tasks in order to relate them to higher-level time processing. Additionally, there are related processes that have not been researched at all, such as passage of time judgements (how quickly time seems to pass) and temporal processing and information processing rates. The latter is interesting, since work in NT population is suggesting that there is at least a strong correlational (perhaps causal) relationship between the rate of the internal clock and the rate at which people can process information, with faster information processing rates associated with higher internal clock speeds (Droit-Volet, and Zélanti, 2013; Jones, Allely and Wearden, 2011).

When reviewing the literature on time perception in autism there are two related issues across the categories of timing tasks which are likely to contribute to the variability in findings. Firstly, studies tend to use small sample sizes. This is part of a wider issue with power and replicability in the psychological sciences (see Button et al. 2013), but is likely to be particularly problematic when attempting to make inferences about such a heterogeneous condition such as autism. Second, the literature utilizes a variety of different methodologies (in terms of procedures and data analysis). As consequence, it is difficult to directly compare results in autism studies with previous research in neurotypicals. For instance, a frequent issue in studies working with a supra-second range is chronometric counting, which normally violates scalar timing as subdividing the duration into smaller units makes the timing on longer durations less variable than for shorter ones (the opposite to the Scalar property). Although some studies (as Martin et al. 2010) have addressed this, not all studies have done it, or they use different methods to do so, making the direct comparison between studies difficult. These methodological differences are likely to contribute to the mixed findings previously exposed in time sensitivity and interval timing.

There is a remaining question about whether deficits in any type of timing actually have any importance in terms of autistic symptoms (for a discussion about possible links see Boucher 2001, Allman and DeLeon, 2009, Allman 2011). A related question is how enhanced time perception abilities impact everyday life activities in comparison with impaired abilities. A possible question that can be addressed in future research is whether autistic people follow a different developmental trajectory in their time perception abilities. Also, it is unknown (even in the NT population) how abilities or deficits in different types of timing map on to each other (if at all). So, do problems in fundamental timing processes predict problems with higher order processing of time and/or vice-versa? This would be a fruitful avenue of investigation as the results would be of value in both understanding how deficits in timing predict/cause atypicalities in other cognitive processes and in everyday activities in autism, and how performance in different types of timing map on to each other in the general population, which remains largely unexplored. Finally, a limitation of this systematic review was the omission of the concept 'timing' in the systematic search. The reason of its exclusion was that 'timing' is a very wide concept that is used to refer to many different processes other than time perception. Nevertheless, we included in the search concepts and methodologies (see methods section) that are used in time perception research, decreasing the likelihood of missing relevant studies.

In summary, previous research has attempted to characterize time perception in autism, but important questions remain unanswered. Our classification of the timing tasks in three hierarchical levels has revealed a different pattern of results at each level. This raises a question about this differential vulnerability autistic individuals have for each level of complexity. A possible explanation is that the fundamental timing mechanism in terms of an internal clock is preserved in autism: if one of the main differences between the three levels is their complexity in the cognitive resources needed, then the differences could be explained by the involvement of those other cognitive processes. The strategy we propose for resolving these issues follows two main principles: (a) to assess at least one measurement of each level of time perception in the same sample avoiding modifications of the original task (e.g. time sensitivity thresholds; interval timing by estimation and comparison methods –verbal estimation and temporal generalisation–; retrospective timing; TBPM; memory for temporal order); (b) to make use of computer modelling in order to explore any specific atypicalities in the pacemaker, memory, or decision making stage of SET model (involving at least one non timing control task e.g. pitch).

Characterising time perception abilities in autism by working with a taxonomy of timing abilities (time sensitivity, interval timing and higher-level time processing) would improve precision in how timing is measured and should encourage attempts to replicate findings at each level, avoiding the generalisation of findings from one level to another level. Finally, having a characterisation of each level as a separated process will facilitate the future design of targeted interventions, if they are needed.

2.7.References

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3. Chapter 3: Investigating the Relationship between Time perception and Autistic Traits

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3.1. Abstract

Time perception, the ability to perceive the duration of stimuli and events, plays an important role in everyday life activities. Temporal judgments are either made prospectively (when the participant is aware that a time judgment will be required) or retrospectively (when an unexpected time judgement is required). Personal accounts and reports from clinicians, parents and caregivers have suggested difficulties with time perception in Autism Spectrum Conditions (ASC). However, evidence is mixed and there is no clarity about what type of time perception abilities are affected, or whether similar patterns of time perception performance can also be seen in general population. In this study, we conducted two experiments to explore the relationship between prospective and retrospective time perception abilities and autistic traits in a sample of undergraduate students (N_{exp1} = 299; N_{exp2} = 138). Two prospective time experiments were conducted (verbal estimation task and temporal generalisation tasks). Additionally, both experiments included a retrospective time question, and a questionnaire to measure autistic traits. There was no relationship between the presence of autistic traits and performance of the participants in the verbal estimation, temporal generalisation, and retrospective tasks. These findings suggests that fundamental prospective judgements of duration (as measured in the verbal estimation task) and the encoding, storage, retrieval and comparison of stimulus durations (as measured by temporal generalization) are not affected by autistic traits in general young adult population. Therefore, the problems with time described in ASC may be related to other cognitive processes, or other higher order types of timing, rather than a pure deficit in duration.

Keywords: Time perception, autism, time estimation, retrospective timing, autistic traits.

3.2.Introduction

The ability to perceive and discriminate the temporal characteristics of stimuli in the environment, is crucial for many everyday life activities such as cause-effect reasoning, elaborate accurate predictions of expectations of when an outcome will be present in the environment and coordinating actions with others. In the past fifteen years, the interest in investigating time perception in clinical populations has grown because it allows a different approach to understanding time perception, and at the same time it may contribute to a better understanding of those clinical conditions (Allman and Meck, 2012). Difficulties with time perception are commonly reported in ASC, both in self-reports from autistic individuals and personal accounts of caregivers and professionals who have usual contact with them (for personal accounts see Boucher, 2001). However, there is no clarity about whether the reported issues with time perception in ASC are due to pure time perception atypicalities or whether they are related to other non-timing cognitive processes (such as memory or attention) that play a role in temporal judgements. In addition, it is not known how any possible impairment in time perception could be related to the social and non-social symptoms that classically characterize autism spectrum conditions. This study aims to explore possible relationships between judgements of temporal duration with autistic traits in the general population.

Sensory atypicalities in autism have been reported across different sensorial systems (Leekman et al., 2007), however there is a big heterogeneity in terms of how these atypicalities are expressed in the autism spectrum (Uljarevic et al. 2017). For example, hypersensitivity has been reported in auditory stimuli in autism (O'Riordan and Passeti, 2006; Gomot et al. 2002), with a trend to have enhanced perceptual abilities in basic features of auditory stimuli such as pitch or loudness (Mottron, et al., 2006; O'Connor, 2012). These sensory atypicalities have also been associated with subclinical autism in studies in general population with presence of autistic traits, which are a group of *autistic like behaviours* that have been shown to be normally distributed in general population (Constantino and Todd, 2003). The most widely used instrument for the assessment of autistic traits in the general population is the Autism Quotient (AQ) developed by Baron-Cohen et al. (2001), which assess the presence of behaviours that are believed to be common in the autistic population, clustered in five sub-scales (communication, social behavior, imagination, attention to details, and attention switching). A study conducted in the UK with 212 participants showed that autistic traits as measured with the Autism Quotient (AQ) are normally distributed, and that atypicalities in sensory responsiveness are associated with stronger autistic traits (Robertson and Simmons, 2013). Another study from Horder et al. (2014) assessed autistic traits on 772 participants with the Autism Quotient (AQ, Baron-Cohen et al., 2001), and showed how autistic traits were related with atypical sensory experiences using three different questionnaires. Although, the correlation values spanned from weak to moderate (from 0.33 to 0.48), a subsample of 23 participants who reported they had a diagnosis of autism showed higher correlation values (from 0.44 - 0.65). However, time perception does not share the same characteristics of the sensory-perceptual systems such as audition or vision (there is no transduction process or stream of information to be decoded), so conclusions from studies in sensory systems – although suggestive of atypicalities – cannot be directly generalized to the perception of durations.

The perception of durations is commonly studied under what is known as interval timing, which involves prospective and retrospective judgements. Prospective temporal judgements are those judgements about the duration of stimuli or events when people know in advance of the event that such a judgement is going to be required. One of the most popular cognitive models of how these judgements are made is Scalar Expectancy Theory (SET), first developed by Gibbon (1977) in studies with animals, and subsequently modified and applied to humans (e.g. Wearden, 1991). Basically, the model consists of three stages: (1) an internal clock stage, constituted by a pacemaker, a switch, and an accumulator; (2) a memory stage, with reference and working memory components; and (3) decision-making process (Gibbon, Church and Meck, 1984). The model entails two main properties of timing (Wearden and Lejeune, 2008). The first property is mean accuracy, and states that the mean estimate of a particular duration will be an average of that physical (real) duration. The second property is the scalar property of the variance, which is that the dispersion around the mean estimation of a duration, varies with that duration. So, this property describes a linear function between the standard deviation of the mean estimates and their mean (Wearden, 2016). So, a possible impairment in prospective time could be reflected on the components of the SET model, or in hypothetical differences in the two properties of scalar timing (i.e. as an indicator of a temporal system governed by different rules). As shown in Casassus et al. (2019), research evidence about the prospective time in autism is not univocal and studies showing impairment in autism have not been able to specify which component of SET are compromised.

There are two main clusters of tasks to assess prospective timing (as explained in Casassus et al., 2019): (a) comparison methods, and (b) estimation methods. Comparison methods are those where a first stimulus is presented and one or a series of comparison stimuli are presented to be compared with the first stimulus. Common tasks in comparison methods are temporal generalization, bisection, and pair comparison. In estimation methods, the participant is asked to give a judgement by executing an action. The most common tasks include verbal estimation, temporal reproduction, and temporal production. This study presents two experiments using one task from each cluster. The first experiment used a verbal estimation task, while the second involved a temporal generalization task (see methods for details).

Estimation methods have been used to research prospective time perception in ASC using Verbal Estimation, where a stimulus is presented to participants who estimate how long the stimulus lasted for in common physical units, such as seconds or milliseconds. To date, only two studies have used verbal estimation with autistic samples, finding no differences between autistic and neurotypical children (Wallace and Happe, 2008) and adults (Sperduti et al. 2014). Other estimation methods for prospective time such as production and reproduction of durations (with the caveat that they add a motor response), have shown poorer performance in ASC relative to controls (Szelag et al. 2004; Martin, Poirier and Bowler, 2010; Brenner et al., 2015; Karaminis et al., 2016). Maister and Plaisted-Grant (2011) also found differences between groups using a temporal reproduction of durations spanning from 0.5s to 45s, however these differences were not present across all the durations they used. The exception is the Wallace and Happe (2008) study described above, who reported no differences in either production or reproduction (in addition to the verbal estimation task).

In the general population only a few studies have looked at how autistic traits affect time perception (disregarding the methods employed), and no clear pattern has emerged. Working with a sample of 24 university students, Stewart et al. (2018) showed a significant negative relationship between autistic traits, and temporal, pitch, and intensity (loudness) thresholds. Working with unfilled durations, the authors observed higher temporal discrimination abilities in individuals with a higher presence of autistic traits. Nevertheless, the same study did not find a correlation when they used a variable standard duration instead of a fixed one (see Stewart et al., 2018 for details). Donohue et al. (2012) found that a bias towards perceiving auditory stimuli before visual stimuli in a simultaneity judgement task was correlated with higher autistic traits in the general population. However, whether simultaneity judgements and prospective time processes are underpinned by the same cognitive process is a current matter of debate. Jones et al. (2017) used a temporal bisection task to research responses to emotionally charged stimuli (faces), and wildlife images. Working with a sample of 84 university students they did not find significant correlations between autistic traits and measures of time perception performance (such as the bisection point and Weber ratio) in the bisection task. However, the evidence regarding whether autistic traits affect the internal clock is scarce, and the Jones et al. (2017) study is (to the best of our knowledge), the only study that has used prospective timing tasks to assess autistic traits in the general population. It is thus important first to replicate Jones' study findings, but also expand on them by using other prospective time tasks. This is the first study exploring the possible influence of autistic traits on time perception using both verbal estimation and temporal generalization tasks.

A problem in the study of the perception of durations comparing between groups is that differences in the tasks cannot be directly attributed to differences in the clock speed (i.e. the pace of the pulses in the pacemaker component of SET, see Wearden and Jones 2007 for full exploration of this issue). The reason for this difficulty is that there is not an absolute value of pulses in the internal clock for a given duration as a constant between individuals. For example (and hypothetically speaking), imaging we have two artificial pacemaker systems: (A) and (B). System A 'ticks' 60 times in a second, while system B 'ticks' 120 times in a second. If you present a beep (a tone) of 60 seconds to those two systems, both will judge that beep as 60 seconds, although system B has a pacemaker twice as faster than system A (for a full discussion see Wearden and Jones, 2013). Therefore, differences between groups in the perception of durations are often anchored in components of the SET model other than the pacemaker. However, there are tasks that allow making inferences about group differences in the pacemaker (subject to certain assumptions). When comparing performance after manipulation of the internal clock (e.g. click trains preceding the stimulus. For an example of this procedure see Wearden et al., 2009), the Verbal Estimation task shows a multiplicative effect (a form of Weber's Law), where difference between the experimental condition and the control becomes larger as the duration to be judged increases its value (Wearden, 2015). The value of the slope of the estimations plotted against stimulus duration would give both a measure of sensitivity, and theoretically an indication of relative internal clock speed (i.e. assuming that in the absence of an external stream of information of 'time', what it is being 'sensed' is an internal clock of some sort). In addition, differences in the intercept are attributed to the moment in which the *switch* component of the internal clock activates and deactivates (related to an attentional resource), with an effect that is additive instead of multiplicative (Williams et al., 2019). Therefore, if a correlation is described between the slope values and another variable (such as autistic traits) it could be inferred that the one or more components of the SET model is modulated by the presence of that other variable. This problem can also be addressed by modelling the data of a Temporal Generalization task. The Modified Church and Gibbon (MCG) model developed by Wearden (1992) allows comparing possible differences between groups on the variability of their memory for duration (of the standard), and decision bias. Experiment 1 presents data from a verbal estimation task and Experiment 2 a temporal generalization task. This design will allow us to overcome the problem of between group comparison, and if the results show a relationship between autistic traits and the perception of duration, it will be possible to hypothesize what factors explain those differences.

Retrospective time judgements are judgements performed without having been advised that such judgement was going to be required before presentation of the stimulus, so no explicit attention was directed to the event to be timed. This produces a methodological challenge, because this judgement can only be performed once in an experimental situation, as any following judgment would be then prospective. It is believed that retrospective judgements are influenced by the complexity of the stimulus to be timed (Block and Zakay, 1997), and/or the number of events that occurred during the period to be judged (Hicks, Kinsbourne and Miller, 1976; Wearden, 2008). Thus, complex stimulus and periods with more events would be judged as longer (for a full discussion on retrospective judgement see Wearden, 2016). In the only study that has researched retrospective judgements in autism, Isakson et al. (2018) asked 17 autistic children with a diagnosis of Asperger syndrome and 17 matched controls participants to estimate the time they spent during a "dull" or "interesting" break during a larger experiment. Although for reasons previously described it can be argued that the second break is a prospective time judgement instead of a retrospective one, no differences between the typically developed group and an autistic group were found for either judgement. To our knowledge, the present study is the first that has attempted to relate prospective and retrospective time with autistic traits in a large sample.

In the first experiment a time estimation task was used to explore relationships between autistic traits and perception of durations. In Experiment 1 it is expected that if autistic traits affect the perception of durations, this will be reflected in the slopes of the estimations (i.e. with steeper slopes suggesting longer estimations).

3.3. Experiment 1: Verbal estimation

3.3.1. Methods

3.3.1.1. Participants

360 undergraduate and postgraduate students from the University of Manchester participated in this study, from which 287 were females and 66 were males, with mean age of 19.62 yrs (SD = 2.05 yrs) and 21.24 yrs (SD = 5.98 yrs) respectively. After the removal of outliers and incoherent data, the data from 299 participants

was analysed (see details in results section). A power analysis to estimate the sample size based on the previous findings from Jones et.al. (2017) and the correlation between autistic traits and prospective time indexes (highest reported correlation was -0.16), and a power of 0.8, shows that you would need a sample of at least 304 to find a significant effect (calculated with GPower 3.1).

3.3.1.2.Materials and procedure

As this was an online study, the main material used in the experiment was a computer with access to internet. Participants accessed a virtual platform where the study was explained, they could complete the consent form, and agree to the study conditions. The experiment consisted of 3 tasks, which were presented in the same order for all participants: (a) Auditory Verbal Estimation of Duration Task; (b) the abridged version of Autism-Spectrum Quotient (AQ-short) (Hoekstra et al. 2011); and (c) Retrospective Timing Question.

It is important to mention that the experiment used the full computer screen, so the usual desktop clock in the down-right corner of the screen was hidden.

Verbal Estimation of Duration: On the first screen, the instructions of the task were presented. The participants were instructed to listen to a word through headphones and to type it in a given field, so they could be sure their sound system was working correctly and at a comfortable volume. Then the participants had a training trial as an example of how the task worked, where they heard a tone of 1000ms and they had to type in their estimate. The task was exactly as the training trial: the participant listened to a tone, and then they needed to type how long that tone was in milliseconds (ms). Eight different tones between 50ms and 1500ms were presented (77, 203, 348, 461, 582, 787, 1065, 1183ms) three times each in a randomised order. Following the recommendation from Wearden (2016), the participants were informed that all the durations would span between 50 – 1500ms, so no responses outside these limits were allowed, decreasing the probability of responses distorting the mean and variability of the estimations. This set of stimuli is the same that has been used in previous research in the lab (e.g. Jones et al., 2009) .No feedback was given, the participants were able to play each duration only once, and each tone was presented separetely, so the participant was focused in only one stimulus at a time. An example of the task can be found in the following link: http://sites.psych-sci.manchester.ac.uk/projects/16125/index2.asp

Autism-Spectrum Quotient: The short version of the Autism-Spectrum Quotient (AQ-short) is a 28 items scale (instead of the 50 items in its original version) that assesses behaviors and preferences that usually characterise ASC, including the two main factors of the original version (Social Behaviour, and Numbers and Patterns). The scale consists of a four-option Likert, where each item is a statement that the assessed individual can answer from 1-4 (definitely agree; Slightly agree; Slightly disagree; and definitely disagree). The AQ-short has a reported internal consistency between .77-.86 and good standard of accuracy, with sensitivity.94 and specificity .91 for a cut point ≥ 70 for clinical significance (see Hoekstra et al. 2011 for more details).

Retrospective time Task: After answering the AQ-short, a screen appeared asking the participants to judge how long they had spent participating in the study in minutes and seconds:

How long has passed since the beginning of this experiment (when you pressed begin)?

Please be as accurate as you can, but do not look at the clock.

(minutes:seconds e.g. 10:25 for 10 minutes 25 seconds or 01:42 for 1 minute 42 seconds)

Then a second screen asked them if they had looked at a clock to make such estimation. Participants answering yes, were excluded from analysis.

3.3.1.3.Data analysis

Verbal estimation: First treatment of outliers was conducted using the Median Absolute Deviation (MAD; Leys et al. 2013) on the values of the slopes. Correlational analysis was used to determine whether there was a relationship between the slopes and intercept values in the verbal estimation task and the scores in the AQ-28 questionnaire (and its two main components). Additionally, the autistic traits were split into 4 levels according to the quartiles in the AQ-short from low to high traits in order to compare groups of high and low autistic traits. This strategy will allow the comparison of possible differences between extreme scores in the AQ, that may not be captured by the correlational analysis, where scores in the middle range of scores may mask differences between the extremes. Also, a Generalised Least Squared (GLS) model was used to show whether the participants correctly distinguished between the different durations in the time estimation task. Levels of autistic traits were included in the model to show if the ability to discriminate between the different duration changes between levels.

The retrospective question was analysed using 4 different indicators. The target time (actual time to be estimated) was compared between the different levels of autistic traits, to find out whether individuals with high traits and low traits were estimating similar or comparable durations (the target depends on how long they take answering the verbal estimation task and AQ-28). The retrospective judgement is the raw estimation individuals give in the unit of seconds. The difference 'target-estimation' provides a measure of whether a participant has overestimated or underestimated the duration. Finally, the Accuracy was calculated by the absolute difference of target – estimation, divided by target, so all the estimations are in the same scale disregarding the actual target each participant was estimating.

3.3.2. Results

3.3.2.1. Verbal estimation task

Outliers treatment was conducted using the Median Absolute Deviations calculated from the individual slope values of the Verbal Estimation task (MAD; Leys et al. 2013). After this procedure 21 participants (slopes < 0.4405 or > 1.707) were removed from the data. Finally, another 41 participants with missing data on their AQ scores were also removed (see Appendix A.1 for characterisation of the outliers). The final sample consisted of 298 participants from which 241 women and 58 males with a mean of age of 19.62 yrs and 20.86 yrs respectively. Shapiro-Wilk test showed that scores from the AQ-short showed a normal distribution ($w = 0.991$, $p = 0.79$). Figure 3.1 shows the distribution of the AQ-short in the full sample.

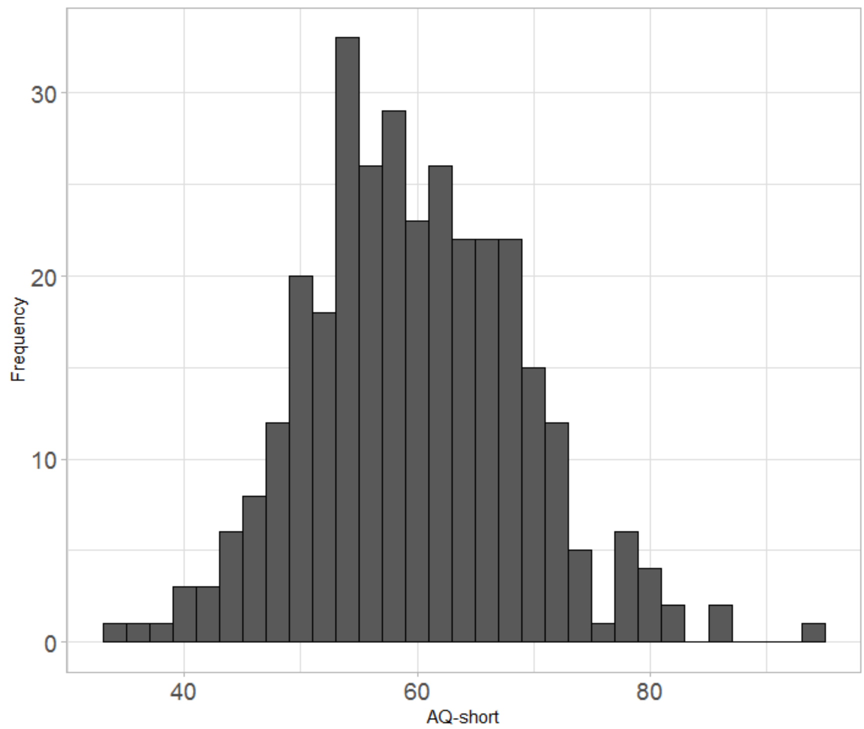

Figure 3. 1: Distribution of AQ-short scores

Overall the sample had a mean of AQ-short of 60.01 (SD = 9.2), with scores ranging between 34 and 94. Panel A of Figure 3.2 shows the verbal estimations plotted against the stimulus duration in the full sample, and the best fitting slope, panel B shows the coefficient of variation plotted against the stimulus duration. General performance on the verbal estimation task showed a slope value of 1.065, which indicates good adjustment to scalar timing. In terms of sensitivity to time, inspection of the data from the coefficient of variation suggests that the participants were more sensitive to longer stimuli than shorter ones (Figure 3.2).

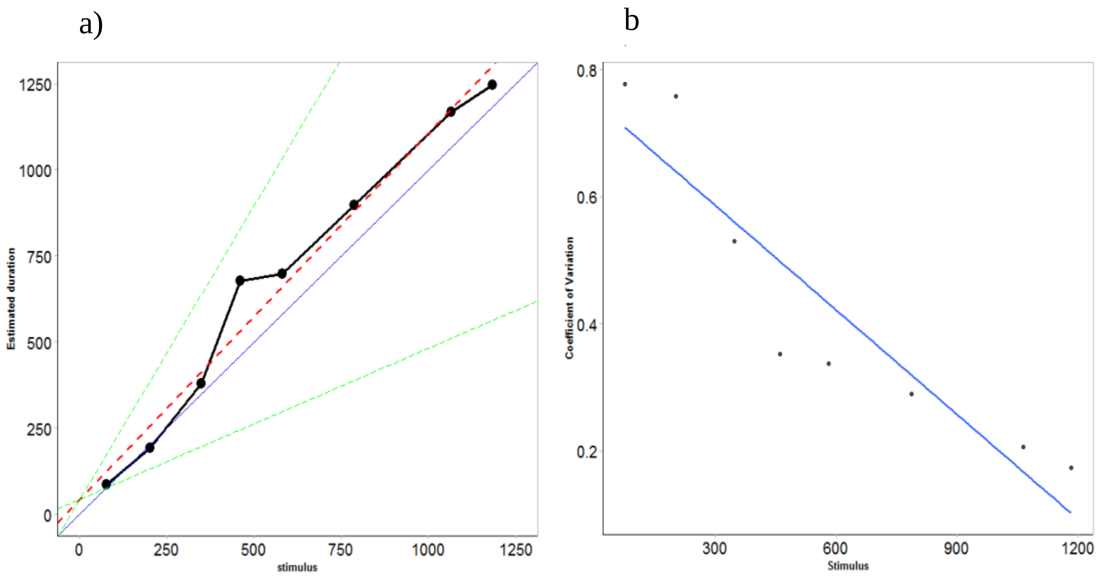

Figure 3. 2: Slope of verbal estimation task and coefficient of variation. (a) Black line and dots show the mean verbal estimates. Solid blue line indicates a hypothetical perfect slope; red dashed line is the slope of the sample; green dotted lines indicate the limits for the treatment of outliers. (b) The mean coefficient of variation plotted against the stimulus duration.

Figure 3.3 depicts scatterplots between the AQ- short and the individual values of the slope and intercepts of the participants. Inspection of the figure suggests no pattern of correlation of AQ-short with either the slope or intercepts values. This was supported by the regression analysis which found no relationship between autistic traits and slopes or intercept (F = 0.422, R2 = 0.001, p = 0.517; and F = 0.303, R2 = 0.001, p =0.582 respectively). Additionally, Bayes Factors showed positive evidence of the absence of correlation between autistic traits with slopes (r_{median} = 0.35, BF = 0.17), and intercept (r_{median} = -0.03, BF = 0.16). In the analysis of the two main components of the AQ-short, slopes did not correlate to Numbers and Patterns (r = 0.0006, p = 0.99, BF = 0.13), nor Social Behaviour (r = 0.0412, p = 0.477, BF = 0.17).

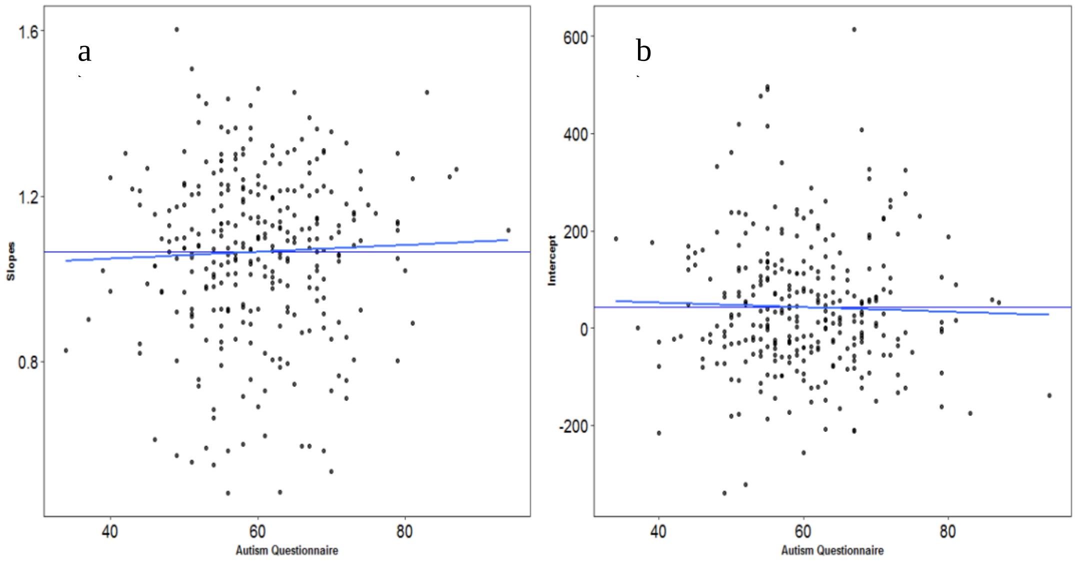

Figure 3. 3: Scatterplot and regression lines for score of AQ-short and values of slopes (a) and Intercept (b).

In order to determine possible differences between levels of autistic traits, the sample was split in four levels according to the quartiles of the AQ-short scores. Table 3.1 shows that AQ-short correctly discriminates between the four levels of autistic traits (so the four level actually differ from each other), but that the values of slopes and intercept do not statistically differ between each other.

Table 3. 1: Mean scores of AQ-short, slopes and intercept in the four levels of autistic traits

AQ level	**n**	**AQ**	**Slopes**	**Intercept**
Low (1)	79	49.23 (4.42)	1.05 (0.22)	42.21 (143.13)
Mid-low (2)	74	56.88 (1.48)	1.08 (0.2)	55.59 (134.73)
Mid-high (3)	71	62.63 (1.85)	1.06 (0.19)	27.94 (113.26)
High (4)	75	71.96 (5.44)	1.07 (0.19)	43.59 (148.29)
F		505.4	0.362	0.502
p value		<0.0001	0.781	0.681
Bayes Factor		113.3	0.003	0.005

To check whether the levels of autistic traits differed between each other in their estimates we first plotted the participants' estimations of each level against the stimulus duration, as is shown in Figure 3.4. A generalised least squared model (GLS) was conducted with a successive difference contrast analysis showing that participants correctly distinguished between all the stimuli durations (F = 2255.692, p < 0.0001), with the exception of the pair 461 – 582ms (t = 0.998, p = 0.319). In the analysis of the interaction between stimuli and level of autistic traits, no interaction was found (F = 0.725, p = 0.811).

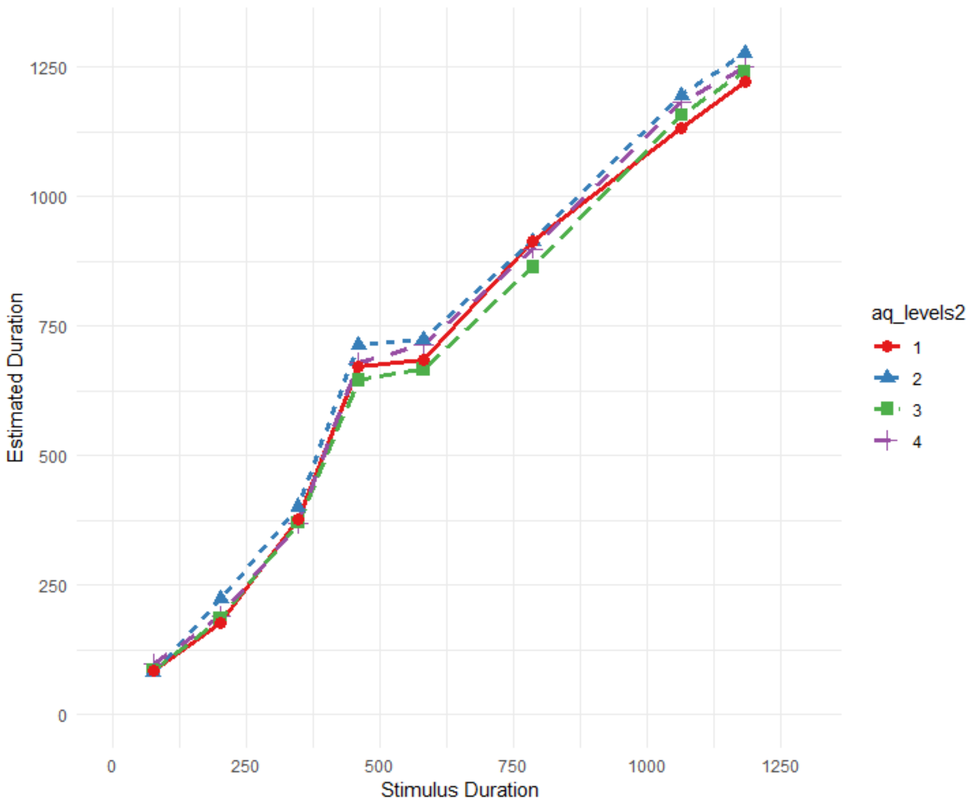

Figure 3. 4: Duration estimates for each level of autistic traits. The different lines represent the levels of autistic traits: Red 1: (Low); Blue 2: (Mid-low); Green 3: (Mid-high); and Purple 4: (high). The figure shows similar performance in the four groups.

3.3.2.2. Retrospective timing

For the retrospective task analysis a treatment of outliers was conducted using MAD (Leys et al. 2013) over the values of the difference between the target duration - estimation. As result four participants were excluded. Another fifteen participants were excluded because they answer that they looked at a clock during the experiment, so the retrospective task analysis was conducted in the remaining 279. The average target time in seconds was 351.66 (SD = 123.72), and the average of the retrospective judgment was 483.7 (SD = 191.52), which indicates a tendency to overestimation and moderate level of accuracy with a value of 0.52 (SD = 0.43) (with 0 being perfect accuracy). A Pearson correlation showed a correlation between the retrospective judgement and the target time ($r = 0.518$, $p < 0.001$), suggesting some adjustment to scalar timing since the temporal judgements increase with the magnitude of the target. In the analysis between retrospective judgements and autistic traits, no correlation was found for either target time ($r = 0.003$, $p = 0.964$), retrospective judgement ($r = 0.061$, $p = 0.309$), or retrospective accuracy ($r = 0.075$, $p = 0.209$). In the analysis by level of autistic traits, Table 3.2 summarises the raw durations for the retrospective question (target), the retrospective judgement, the difference in seconds between the target and the judgement, and the accuracy index on each level of autistic traits. Kruskal-Wallis analysis showed no statistical difference between the four levels of autistic traits on either, the target time, the retrospective judgement and the accuracy index. Although there were no statistical differences, there is a trend to worse accuracy in the higher levels of autistic traits. To explore this further, a Pearson correlation were performed and it showed no correlation between the accuracy index of the retrospective task and the two main components social behaviour (r = 0.049, p = 0.408) and numbers and patterns (r = 0.078, p = 0.199).

Table 3. 2: Performance on the retrospective task (ms) level of autistic traits

AQ level	Retrospective question (target)	Retrospective judgement	Difference Q-J	Accuracy
Low (1)	357.18 (124.8)	475.92 (208.3)	-118.74 (164.7)	0.48 (0.38)
Mid-low (2)	325.24 (78.4)	450.94 (164.8)	-125.7 (154.1)	0.52 (0.43)
Mid-high (3)	369.46 (151.9)	501.09 (205.3)	-131.63 (168.7)	0.48 (0.48)
High (4)	355.79 (128.4)	509.12 (182.9)	-153.33 (176.6)	0.59 (0.42)
Kruskal-Wallis Chi^2	3.599	4.113	2.539	4.798
p value	0.308	0.249	0.468	0.187

3.3.2.3.Relationship between prospective and retrospective tasks

Finally, no correlation was found between either the slopes of the verbal estimation task and the retrospective time accuracy (r = -0.11, p = 0.069), or between slopes of the verbal estimation task and the difference target – estimation in the retrospective task (r = 0.04, p = 0.555). This absence of correlation suggests the presence of different cognitive mechanisms underpinning prospective and retrospective judgements.

3.3.3. <u>Discussion</u>

Experiment 1 had as its main hypothesis that there should be a correlation between the AQ-short and the slopes on the verbal estimation task. However, we found that the strength of autistic traits was not related to the performance in the verbal estimation task. Additionally, no correlation was found between autistic traits and the intercept values, which is an index associated to the attentional resources in place during the task. Furthermore, we split the sample in four levels of autistic traits, finding no differences between groups for either slopes and intercepts. These results suggest that the estimation of duration, and in turn the fundamental operation of the internal clock, is not modulated by the presence of autistic traits.

For the retrospective task, there was no correlation between the retrospective judgement and autistic traits. Additionally no statistical differences were reached when comparing the four levels of autistic traits. These results suggest that the ability of estimating durations based on the memory of the events that just occurred (or any alternative method by which retrospective judgements are made) are independent of the strength of the presence of autistic traits. The presence of a correlation would have indicated for example that those individuals with steeper slopes in the verbal estimation task, and so, a tendency towards overestimating durations that would increase with the stimulus duration, would have also overestimate their retrospective judgements of duration.

Although time estimation is a very informative task, that allows temporal judgements to be assessed in physical units that are familiar for everyone (e.g. seconds), there are questions that could not be addressed with just this task. If we assumed that autistic traits do not affect the fundamental clock component of the timing system, it is possible that the atypical temporal experiences reported by autistic individuals are anchored in the memory or decision components of the SET model instead, which is something that has been suggested before, especially in what concerns working memory processes (Casassus, et al. 2019). To address this question we conducted a second experiment using a temporal generalisation task, because it uses more involved memory and decision processes. Additionally if differences are observed between the groups then SET computer modelling will allow us to assign the differences to either memory or decision operations (or both).

3.4.Experiment 2: Temporal generalisation

Few studies have researched time perception in autism using comparison methods. Temporal generalization has been used to compare the perception of duration between autistic individuals and the typically developing population in two previous studies. Falter et al. (2012) used a temporal generalization task in the visual, auditory and audiovisual modalities. Through signal detection analysis, this study showed lower temporal discrimination in the autistic group, especially on the auditory version of the task. This study also found good adherence of both groups to the scalar property, although this was even clearer for the autistic group. Additionally, they found that in the autistic group a more conservative response bias was associated with communicational symptoms. Brodeur et al. (2014) worked with a temporal generalization task in a sample of 15 low-IQ autistic children and matched controls for mental age, finding poorer performance in the autistic group.

Temporal bisection has also been used to compare autistic individuals to neurotypicals on prospective time abilities, but with mixed results. While Allman et al. (2011) found differences between groups, Gil et al. (2012) and Jones et al. (2017) found comparable performance. Finally, Lambretch et al. (2018) used a modified version of a temporal generalization task (more similar to a pair comparison task; for further discussion see Allan, 1979; Wearden and Ferrara, 1993; and Penton-Voak et al., 1996) to compare the performance of autistic adults and matched controls while they were measured on a magneto-encephalogram (MEG), finding poorer temporal discrimination abilities in the ASC group, and less allocation of neural resources to the task.

The current study used a temporal generalization task, because it has proven to be a very robust model to assess the perception of duration since its first development with animal models (Church and Gibbon, 1984). The temporal generalization task also allows for the disentanglement of some of the cognitive processes involved in the task through computer modelling and signal detection theory (for details see Wearden, 1998). Finally, some studies have used versions of the task where participants need to distinguish between pitches or volume intensity (e.g. Jones et al. 2009) as a comparison task, and as a control task (Lambretch et al. 2018). Although it has been suggested that pitch perception is enhanced in autism (see main introduction), which involves the limitation of having control task, that is known to show enhanced performance. However, to the best of our knowledge this is the first time is used in a full temporal generalization task, so it is not clear that those results showing better pitch discrimination in autism, will be transferred to a better performance in the temporal generalization task. This is good practice in prospective time research, because it allows differentiation of whether possible findings are because of a global sensorial atypicality, some unique characteristic of the generalization task (e.g. a pattern of response), or if they are specific for the perception of durations. Accordingly, the second experiment of the current study includes a pitch generalization task as a control task. In Experiment 2 we expect that differences between different levels of autistic traits should be present in the temporal generalization task, but not in the pitch generalization task.

3.4.1. Methods

3.4.1.1.Participants

One hundred and eighty-eight undergraduate students were recruited (independently of study one, but from the same population), from which 148 participants completed the experiments. The final sample was constituted by 138 after the treatment of outliers (see results section for details)[1]. A power analysis to estimate the sample size based on the same parameters of study one. So, it was estimated that significant results for the sample size of the current experiment would have a power of 0.45 (calculated with GPower 3.1).

3.4.1.2.Materials and procedure

Participants accessed a virtual platform on *SelectSurvey* to ensure data protection, where the study was explained, they could complete the consent form, and agree to the study conditions. Then the participants were referred to a second platform on Pavlovia (pavlovia.org), where the experiment was conducted. The whole experiment was built in Psychopy (Pierce et al., 2019). The experiment included 4 sections, which were presented under the same order for all the participants (Fig. 2): (a) Temporal generalization; (b) Pitch generalization; (c) Retrospective Timing Question; (d) the abridged version of Autism-Spectrum Quotient (AQ-short) (Hoekstra et al. 2011). As in Experiment 1, the clock in the screen was hidden during the experiment.

Temporal generalisation: In this task, participants needed to compare a standard stimulus with a series of comparisons. The comparisons were a proportion of the

[1] The data collection was conducted at the same time that the GDPR legislation of data protection started to be applied. Given that the data collection was conducted through pavlovia.org, data from age and sex of the participants was not included in the experiment.

standard duration (both longer and shorter), including 3 presentations of the standard itself (i.e Standard x0.25, x0.5, x0.75, x1, x1, x1, 1.25, x1.5, x1.75). So, the full series of the 9 comparisons constituted one block of 9 trials. After each trial, the participants were asked: *was that the same duration as the standard?* Then, they needed to press ‘y’ or ‘n’, to answer yes or no.

The experiment started with the presentation of the task and its instructions, after which the participants completed three practice trials. They were then told that the practice was over and they were going to receive a new Standard. The Standard stimulus was repeated three times so they could remember its duration. Then a new screen told them that comparisons were going to start. The comparisons were randomised within each block. The presentation of each stimuli was preceded by a SOA from a random selection between 750, 1000 and 1250ms.

There were two versions of the task of 5 blocks. In the first one the Standard was a 400ms beep (i.e. comparisons at 100, 200, 300, 400, 400, 400, 500, 600, and 700ms), while in the second the Standard was a 800ms beep (i.e. comparisons at 200, 400, 600, 800, 800, 800, 1000, 1200, and 1400ms). The order of the presentation was fixed alternating one block of each version of the task. So, a subtask 400ms Standard was followed by a 800ms Standard (and so on). All tones were 500 Hz.

Pitch generalisation: The task was identical to the temporal generalisation, but instead of comparing the duration of a beep, the participants were comparing their pitches. Standards for each subtask were set on 500 Hz and 1000 Hz. Comparison were a rate of the Standard at x0.88, x0.92, x0.96, x1, x1, x1, x1.04, x1.08, x12 (again presented in random order within each block). All tones lasted for 500ms.

After completing the pitch generalisation task a screen said that the pitch task was over and they would need to answer a couple of questions and a short questionnaire.

Retrospective question: A screen with a question about how long they estimated had passed since they started the experiment. There options for response were presented in a table showing grid of numbers from 1 to 60 (figure 3.5):

As accurate as you can, how long have passed since you started your participation in this experiment?

(First black background screen)

Please, give your answer in minutes. Think your answer, look at the number representing minutes in the table and click over your choice.

1	13	25	37	49
2	14	26	38	50
3	15	27	39	51
4	16	28	40	52
5	17	29	41	53
6	18	30	42	54
7	19	31	43	55
8	20	32	44	56
9	21	33	45	57
10	22	34	46	58
11	23	35	47	59
12	24	36	48	60

Figure 3. 5: Grid of numbers to answer the retrospective question

The mechanism of response differs from Experiment one because of limitations of the online platform used in Experiment 2.

Then they were asked to answer honestly if they have had looked at the clock or any time aid device since the experiment started (y/n). Participants answering yes, were excluded from analysis.

Autism-Spectrum Quotient (AQ-short) (Hoekstra et al. 2011): This was exactly the same as in Experiment 1.

3.4.1.3.Data Analysis

A correlational analysis between the proportion of Yes responses on the standard and the scores of the AQ was conducted through Pearson correlations. Then, an index of accuracy in the task was calculated: (True Positive + True Negatives) / 2 (Ogden et al. 2019), and a correlational analysis was used to explore possible relationships between accuracy and autistic traits. A linear mixed model effect was calculated to determine the effect of the comparisons, subtask and autistic traits in the performance of the task. Then, two models were compared with and without the inclusion of the AQ scores as covariant and Akaike Information Criterion (AIC) was used to check which model was a better fit. Finally, pairwise comparisons between the comparisons of each subtask were used to check for superimposition (see introduction of this chapter and relevant section in Chapter 1).

3.4.2. Results

3.4.2.1. Temporal generalisation

Participants were considered as outliers when their responses were inconsistent in 2 or more subtasks. An inconsistent response in a temporal (or pitch) generalisation task was defined as having two extreme comparison values (standard * 0.25; standard *1.75) with more proportion of yes responses than the Standard in one subtask, or one extreme comparison in two or more subtasks (temporal generalisation gradients of outliers, and their AQ-short scores are shown in Appendix A.2). This is a different strategy to treat outliers than in Experiment 1, because the nature of the task and data is in fact different (e.g. using the slopes to the peak, would have taken out individuals with deviant performance, but good quality of data). Ten participants were excluded for these reasons. So, the analysis of experiment two involved 138 participants. As has been shown in previous studies and in Experiment 1, autistic traits were normally distributed as shown by Shapiro-Wilk test (w = 0.991, p = 0.557) with mean 59.31(8.9) (Figure 3.6).

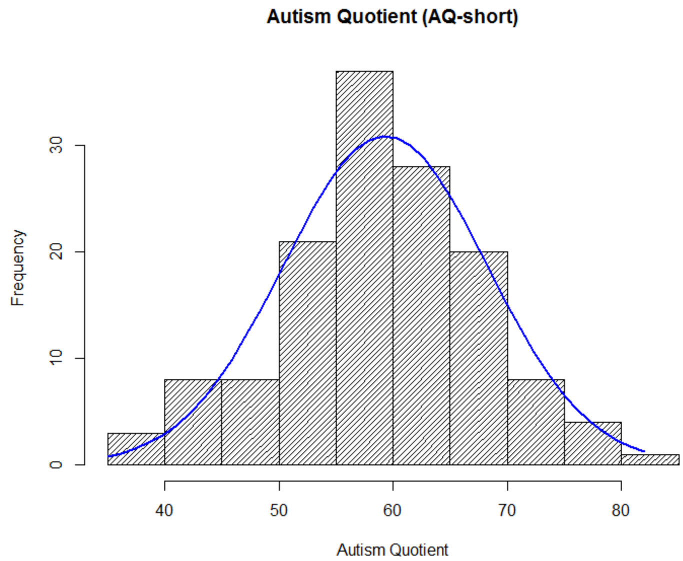

Figure 3. 6: Distribution of the scores AQ-short.

General performance in the temporal generalisation task peaked at the Standard duration for both the 400ms and 800ms subtasks at 0.760 and 0.746 proportion of Yes responses respectively, suggesting typical performance on the task. There was no difference in mean accuracy between tasks (t = -1.789, p = 0.075), which suggests that both subtasks were equally difficult (Figure 3.7). Only the 400ms subtask showed the right skewed gradient that is typical in this task for human adults.

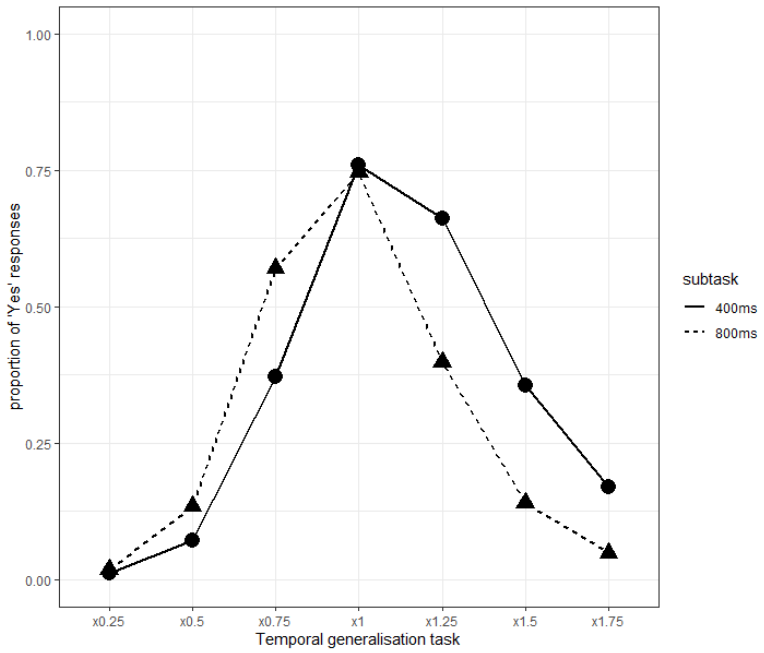

Figure 3. 7: Temporal generalisation gradients for 400 and 800ms standards. The solid line depicts the 400 ms version of the task and the dashed line the 800 ms version

A correlational analysis between the scores of the AQ-short and the proportion of 'yes' responses to the Standard for either the 400ms or the 800ms subtasks showed no correlation (r = 0.087, p = 0.306; $r_{meadian}$ = 0.08, BF = 0.326); r = -0.026, p = 0.758; $r_{meadian}$ = -0.02, BF = 0.206 respectively). The same result was reached in the correlational analysis between autistic traits and the accuracy index of the subtasks (r = 0.147, p = 0.086; $r_{meadian}$ = 0.142, BF = 0.812; r = -0.041, p = 0.629; $r_{meadian}$ = -0.039, BF = 0.220 respectively). A linear mixed model showed a significant effect of the comparison (F = 507.569, p < 0.001), and subtask (F = 28.940, p < 0.001), indicating that in general the participants were able to distinguish between the standard and the different comparisons. The interaction subtask*comparison also showed a statistical effect (F = 44.660, p < 0.001). After including the AQ-short scores as covariant to check if the temporal generalisation data would be better explained with its inclusion, the model resulted on a lower AIC value in comparison to the linear model without the AQ-short scores as covariant (AQ-AIC = -758.43, without AQ-AIC = -759.87), and showed no significant effect (p = 0.45). Post-hoc analysis confirmed the initial inspection of the gradients of each subtasks plot against each other, where it can be seen that there is a differential asymmetry in the gradients. No difference were found between the subtasks for the *0.25, *0.5, and *1.0 comparison/standard ratio (p = 0.764, p = 0.098, p = 0.549 respectively), but significant differences were found for all the other comparison/standard ratios ($p < 0.001$), so superimposition was only partially achieved. While in the 400ms standard subtask were more ‘yes’ responses to durations longer than the standard, in the 800ms standard subtask there were more ‘yes’ responses in the durations shorter than the standard. Figure 3.8 shows the absence of a significant effect of the levels of autistic traits in each subtask (p = 0.63, and p = 0.48 respectively).

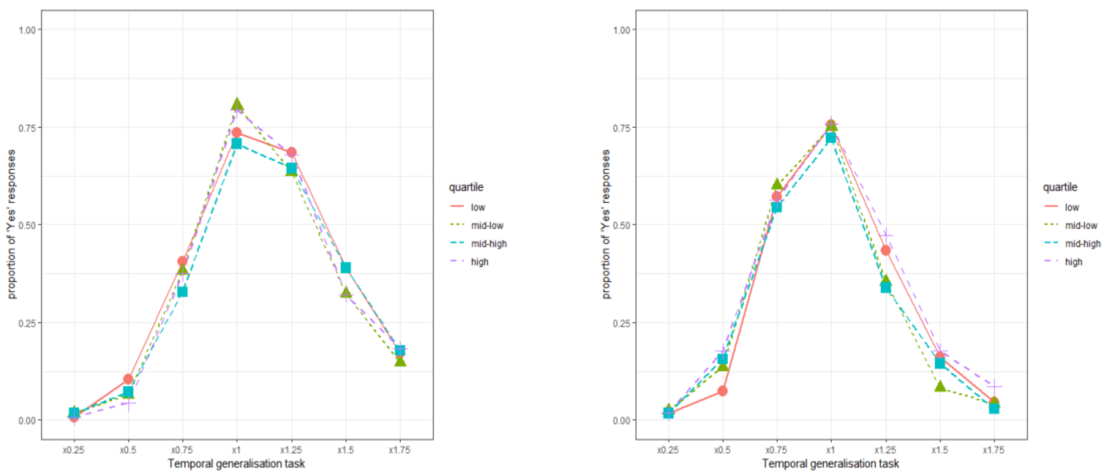

Figure 3. 8: Temporal generalisation gradients for each task by level of autistic traits. The left-hand panel (a) shows the 400ms version of the temporal generalisation task by level of autistic traits as measured by AQ-short. The right-hand panel (b) depicts the levels of autistic traits in the 800ms subtask.

3.4.2.2. *Pitch generalisation task*

The pitch generalisation task showed an accuracy of 0.82 on the 500hz Standard and of 0.80 on the 1000hz Standard, with no significant difference between them ($t = 1.033$, $p = 0.302$). Mean accuracy of the pitch task was statistically higher than the mean accuracy temporal generalisation task ($t = -12.207$, $p < 0.001$), which means that the pitch version of the task was easier than the temporal generalisation task (Figure 3.9).

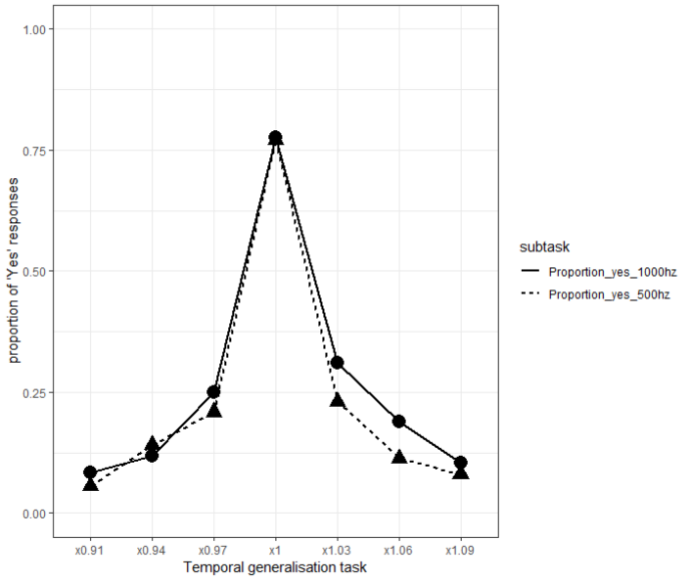

Figure 3. 9: Gradients for both versions of the pitch generalisation task. The solid line depicts the 1000hz version of the task and the dashed line the 500hz version.

The linear mixed model using the comparison and the pitch subtask as factors and the proportion of yes responses as the dependent variable, showed an effect of the comparison ($F = 496.266$, $p <0.001$), subtasks ($F = 16.176$, $p < 0.001$) separately and both factors together ($F = 2.782$, $p = 0.011$), indicating that the two version of the task did not superimpose. Pairwise analysis revealed that this lack of superimposition is justified on differences on the comparisons at x1.03 ($t = 3.637$, $p = 0.02$), and the comparison at x1.06 ($t = 3.505$, $p = 0.031$). When including the

AQ scores in the model as a covariant, the model showed a higher AIC value (-906.16) than without the AQ (-907.74). In the analysis by level of autistic traits no differences were found for the indexes of accuracy for the 500hz version (F = 0.745, p = 0.527) or the 1000hz version (F = 0.317, p = 0.813). Also no significant effects were described for quartile (F = 1. 657, p = 0.180), and comparison * quartile (F = 0.984, p = 0.476). In the version of 1000hz standard, the results showed the same. The factor comparison was significant (F = 216.003, p < 0.001), and no significant effect was found for quartile (F = 0.807, p = 0.492) or comparison * quartile (F = 0.312, p = 0.997) (figure 3.10).

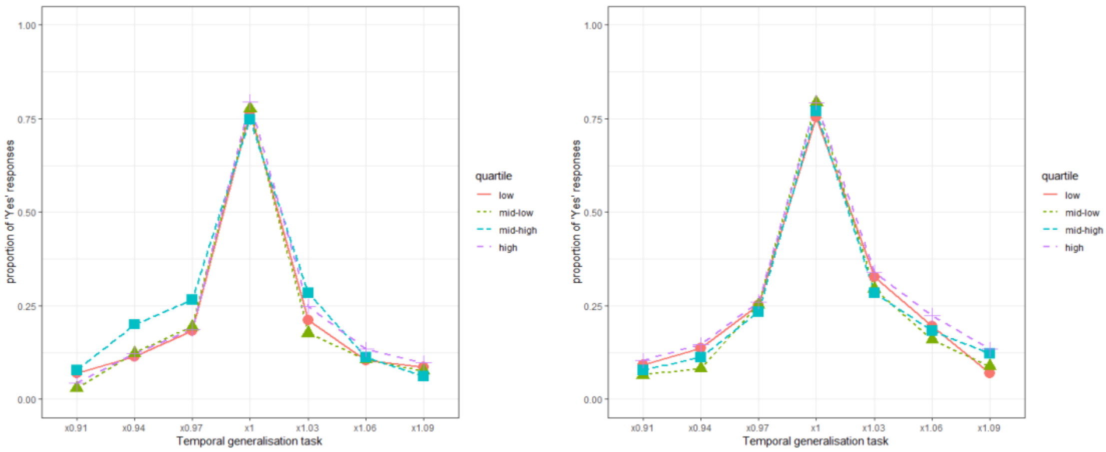

Figure 3. 10: Pitch generalisation gradient in both subtasks by level of autistic traits.The left-hand panel (a) shows the 500 Hz version of the temporal generalisation task by level of autistic traits as measured by AQ-short. The left-hand panel (b) depicts the levels of autistic traits in the 1000 Hz subtask.

3.4.2.3.Retrospective timing

For the retrospective timing task 14 participants were excluded because they expressed they looked at a clock during the task. Additionally, three participants were excluded because their target time was higher than 60 minutes. Finally, the treatment of outliers was conducted as in Experiment 1, resulting in the exclusion of other four participants. As result, the retrospective task analysis was performed with the remaining 122 individuals.

General performance in the retrospective question participants showed a mean retrospective judgement of 759.13s (SD: 197.89) for a mean target of 827.26s (SD: 144.6), with a correlation between target and judgement of $r = 0.349$ ($p < 0.001$). The same treatment to calculate accuracy as Experiment 1 was performed ((target – estimation) / target), resulting in a value of 0.2 (SD = 0.14) suggesting a high level of accuracy (in comparison with Experiment 1). No correlation was found between the retrospective accuracy and the scores of AQ-short ($r = 0.239$ $p = 0.11$). The data on Table 3.3 shows trends for higher target times and lower accuracy with the higher level of autistic traits, although no statistical differences were found between the four levels of autistic traits on the target, judgement, absolute difference or accuracy of the retrospective task.

Table 3. 3: Retrospective time question, judgement, absolute difference in seconds, and accuracy

AQ level	Retrospective question (target)	Retrospective judgement	Absolute Difference Q-J	Accuracy
Low (1)	793.55	774	162.53	0.2
Mid-low (2)	828.94	781.71	126.62	0.15
Mid-high (3)	837.45	808.57	181.94	0.22
High (4)	852.95	711.72	206.57	0.24
Krukal-Wallis Chi^2	3.272	4.774	7.773	7.098
p value	0.3516	0.189	0.051	0.069

3.4.2.4.Correlation between prospective and retrospective timing

A correlational analysis was conducted to determine the possible relationship between the prospective and retrospective timing tasks. No correlation were found between retrospective time accuracy and either 400 ms standard accuracy (r =

0.041, p = 0.658), 800 ms accuracy (r = -0.158, p = 0.093), 500 Hz accuracy (r = 0.089, p = 0.346), and 1000 Hz accuracy (r = 0.049, p = 0.604).

3.4.3. Discussion

In Experiment 2, we anticipated that participants with increased autistic traits would show less accurate performance on the temporal and pitch generalisation tasks, because of the higher involvement of working memory processes (compared to the verbal estimation task in Experiment 1). However, no trends were found in that direction. Firstly, autistic traits did not have an influence on how accurately participants responded in the task. This was true for both versions of the temporal generalisation and pitch generalisation tasks. In addition, after dividing the sample into four different levels of autistic traits (as done in Experiment 1) no differences between groups reached statistical significance either.

The second part of the experiment was the retrospective task. Analysis showed no significant differences between the four levels of autistic traits in target time, judgement, absolute difference or accuracy. This is also reflected by the correlational analysis, which showed no significant correlation between the scores of the AQ-short and the accuracy in the retrospective judgement.

3.5. General discussion

Some studies (and personal accounts) have shown that autism is associated with atypical time perception and time experiences, but previous research shows mixed findings (Casassus et al. 2019). This study aimed to determine whether autistic traits are related to prospective and retrospective judgements of durations in the general population. Experiment 1 showed no influence of autistic traits on the verbal estimation task. This was tested by two different means, first using correlations between the AQ scores and the slope values, and then by comparing the performance in the task between four different levels of autistic traits. Additionally, no effect of autistic traits was found for the retrospective time judgement. Experiment 2 used a temporal generalisation task, where the participant needs to remember the duration of a Standard tone to be compared to a series of comparisons. This task has a higher involvement of working memory and decision/comparison processes, but again we found no influence of autistic traits on the performance of the task, its control task (pitch), or the retrospective judgement. Overall, this study provides strong evidence that prospective and retrospective judgements of durations are not affected by the strength of the presence of autistic traits.

In the verbal estimation task, one of the main indicators of a different speed in the internal clock are the values of the slopes, with flatter slopes showing an underestimation of duration and steeper slopes indicating overestimation. Thus, a positive correlation between AQ scores and slopes would have been consistent with the idea that individuals with higher autistic traits had a faster internal clock (see introduction). However, our study showed no correlation at all, and so no relationship between autistic traits and the internal clock. Additionally, no effects were found for the intercept values, from which it can be inferred that there were similar levels of attentional resources applied during the task regardless of AQ score. As discussed in the introduction, this is the first study researching the possible association between autistic traits and prospective judgements using a verbal estimation task, however these results are consistent with the only two studies with autistic individuals using this task (Wallace and Happe, 2008; and

Sperduti et al. 2014). Interestingly, all the other studies working with autism have used temporal reproduction paradigms instead of verbal estimation, and all of them showed differences between groups. An important remark is that the load of executive function processes is different between temporal reproduction and verbal estimation, where for example temporal reproduction is more influenced by *switching* abilities (Ogden et al., 2014). However, Wallace and Happe (2008) assessed perception of duration using both methodologies (and production), finding no differences in either of the measurements.

We choose to also use a pitch generalisation task, so any possible difference in the temporal version that was not present in the pitch version, could be attributed to time perception abilities and not to global sensory processing, information processing or comparison/decision making processes. However, we found that the inclusion of autistic traits in the statistical model to explain the performance in the task resulted in a weaker model (the data was better explained without using the AQ scores as predictor). Additionally, no significant correlations were reported between accuracy and autistic traits. These results expand findings from Jones et al. (2014) who reported no influence of autistic traits on a temporal bisection task, but in a sample of students without high scores in the questionnaire of autistic traits. In another study working with comparison methods, Stewart et al. (2018) reported a correlation between temporal thresholds and autistic traits; although they measured *temporal thresholds* (a comparison method of time sensitivity instead of interval timing) using *unfilled* durations instead of prospective timing with filled durations. Importantly, unfilled durations have been shown to be estimated as shorter than filled durations (Wearden et al., 2007), which is an effect that has been suggested to be based in differences in the clock speed in the estimation of this type of stimuli in comparison to filled stimuli. Whether the findings of Stewart et al. (2018) are related somehow to these underlying differences between the timing of filled and unfilled durations is a question that requires further research (see Williams et al., 2019 for a further discussion of this issue about filled and unfilled durations).

In the retrospective timing task, both experiments showed no correlation with autistic traits or differences between levels of autistic traits, although both experiments showed a small trend for less accurate responses in the group with high autistic traits. An important difference between the retrospective tasks was that in the Experiment 1 the target time was around 5-6 minutes, while in Experiment 2 the target duration was around 13 – 14 minutes, with participants being more accurate in the longer retrospective target (Experiment 2) than in the shorter version (Experiment 1). Although our results are the same in the two experiments presented on this study, this is an area where more research is needed. Future studies could include a task of memory for duration such as that used by Wearden et al. (2008) in Parkinson's patients, and a task of temporal order memory (Benneto et al., 1996) in addition to other prospective memory timing tasks. This would help us to understand how memory processes/abilities in general may relate to retrospective judgements.

An interesting finding in the retrospective tasks was that retrospective timing showed some adjustment to the scalar properties, showing coefficients of variation similar to those shown in Experiment 1 in short durations (0.82 and 0.7 in Experiments 1 and 2 respectively). Thus, despite the fact that no correlations were found between the prospective and retrospective tasks in either of the experiments, it can be hypothesise that some underlying processes are common for both type of judgements. It is important to notice, that our prospective and retrospective tasks used very different duration, which may be one of the reasons of the absence of correlation between the accuracy of both tasks.

An interesting (although secondary) finding of this research is how well the tasks transfer to an online instead of 'in lab' presentation. In general terms, the verbal estimation task showed the same characteristics that have been shown in the past in lab studies. Slopes and the coefficient of variation showed the typical linear function that has been reported in other studies (e.g. Mathews, 2011; Wearden, 2015; Williams 2019). In the temporal generalisation task, the performance of the participants is also consistent with previous studies (e.g. Wearden, 1992; Jones and Wearden 2003). The only possible exception is in the 800ms standard, which showed a left skew instead of right, although this has been shown before under certain condition such as asking the participant to respond as quickly as possible (Klapproth and Müller, 2008). When the study was planned, there were concerns about all participants responding in their own personal computers, and the lack of control that entails (e.g. not having control of how loud the participants were playing the tones). However, the data showed the same patterns of previous studies in the lab. To our knowledge this is the first online assessment in time perception research, and it has shown to be a very adequate alternative to lab-based measurements and has the distinct advantage of being able to run a much large sample of participants than is practically possible in a lab, increasing by this the statistical power to find possible effects.

It is important to clarify that the current findings cannot be directly generalised to the full autism spectrum. Although the AQ-short has shown to be a good assessment, it is not a diagnostic instrument. Also, it remains unclear how closely related are the time perception abilities measured on this study with more complex timing abilities such as memory for temporal order, or time based prospective memory. This is important because someone with intact abilities in their perception of duration in prospective timing tasks does not necessarily have typical high-order cognitive processes related to time (as is discussed in Casassus et al., 2019). This is a current challenge not only for autism research, but for the time perception field in general.

In summary, our study showed that prospective time abilities were not related to the presence of autistic traits. Also, our online methodology has been demonstrated to be adequate for time perception research and should be encourage, because they allow (for instance) to deal with the common issues of statistical power in retrospective time research.

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4. Chapter 4: Time perception characterisation in Autism Spectrum Condition

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4.1. Abstract

There is a growing belief in researchers, clinicians, parents, and caregivers that there are atypical time perception abilities in Autism Spectrum Conditions (ASC). However, the evidence of timing impairments in ASC is far from conclusive, and it has been suggested that problems with timing in ASC could be anchored on other cognitive processes (e.g. working memory or executive function) instead of a true impairment in the perception of duration (Casassus et al., 2019). This study compared a group of 33 autistic adults and matched controls in a battery of questionnaires and in three experiments assessing different time perception behaviours. The two first experiments are psychophysics tasks assessing temporal sensitivity thresholds and interval timing through a temporal generalisation task. The third experiment is an ecological task assessing time-based prospective memory through a modified version of the Dresden breakfast task, where participants were video recorded while preparing breakfast following a set of rules. Results suggest that at a group level, autistic individuals' performance is comparable to controls in all the tasks. Analysis from those with atypical performance suggest that atypicalities in time perception can be found in autism, but also in neurotypical population. Finally, reflections on theoretical and methodological challenges and the impact of this line of research in clinical settings are discussed.

Key words: time perception, autism, time sensitivity, prospective time, time-based prospective memory.

4.2. Introduction

The previous chapters have covered previous research through a systematic review of the literature on time perception in autism, and a large scale study about the relationship between autistic traits and interval timing. In the systematic review, a hierarchical taxonomy of time perception processes was presented and the previous studies records were clustered into those categories (Casassus et al., 2019). A common characteristic in many studies was that they were underpowered due to small sample sizes. Understanding that working with sufficiently big samples for well-powered studies in neurodiverse populations is a frequent problem for researchers (and considering that autistic traits are normally distributed in the population), a large scale study was conducted in interval timing, which was presented in the previous chapter. The main finding from that large scale study was that autistic traits do not affect how people perceive durations. Or put in a different way, the performance in interval timing tasks is independent of the strength of autistic traits in the general young adult population. However, as was explained in the discussion of the previous chapter, the diagnosis of autism is not the same as strong presence of autistic traits. Accordingly, a logical next step to understand time perception in autism is to compare a sample of autistic individuals to a typically developed control group with a relatively good sample size (i.e. over 30 individuals per group). This is the main focus of the following chapter.

One of the main conclusions of the systematic review was that the different clusters of time perception behaviours had different levels of agreement between studies. Interestingly the level of agreement increased with the complexity of the level in the taxonomy presented. Following that trend, three experiments were conducted in the same population to explore possible differences between autistic individuals and neurotypicals, which is unusual in time perception research in autism (and in other clinical populations), where most studies use only one or two tasks. The first experiment presents a time sensitivity task examined through temporal difference thresholds. From the second level of the taxonomy of time perception we chose a temporal generalisation task (see Chapter 3 and methods section of the current chapter for details of the task), which is presented in the second experiment. Temporal generalisation was chosen instead of bisection, because in temporal bisection is difficult to determine whether the participants respond to the differences between the probes, or because of the comparison of the probe against the standard (for a full discussion see Wearden and Ferrara, 1995). As is explained in Falter et al. (2012) this adds ambiguity to the interpretation of the results. Finally, for the third study it was chosen to work with the Dresden breakfast task (Altgassen et al., 2012), because of its ecological value, and because the initial question motivating this research was related to behaviours that resemble the type of activities in that task.

The chapter is split into 5 sections, one for the general methods and sample characterisation, one for each experiment, and a final section exploring correlations between the experiments. Finally, a general discussion is presented at the end. Within each section the reader will find a brief background with presentation of the task, the hypothesis associated with that experiment and the theory supporting that hypothesis, followed by the methods, results and summary of findings. In order to avoid repetition, whenever reference could be made to material covered in the previous chapters of this thesis this was done.

4.3. General Methods

4.3.1. Participants and characterisation of the sample

The sample consisted of 33 autistic adults (female: 14; male: 19), and 33 neurotypical individuals (female: 12, male: 21) matched by age and IQ (table 4.1). Recruitment was conducted through the list of contacts of the BEAM-lab of the University of Manchester and through virtual platforms. All autistic participants had a confirmed diagnosis from a trained clinician and were asked to bring a proof of their diagnosis in the day of the experiment. Additionally, module 4 of the Autistic Diagnosis Observation Schedule ADOS-2 (Lord et al., 2012) was used by a trained assessor to confirm the diagnosis. Participants from the NT group declared having no direct relatives diagnosed with autism. No participants in either group reported hearing impairments (this was an exclusion criterion), and all participants had normal or corrected to normal vision (glasses). Additionally, a high proficiency in English language at a native level was used as inclusion criteria (e.g. history of study or wok in an English speaking country). All participants signed an informed consent in accordance with the declaration of Helsinki, and the study was approved by the University Research Ethics Committee.

A power analysis to estimate the sample size based on the comparison of 2 groups, a medium effect size (0.5), showed the minimum you would need is a sample of 128 participants (64 per group). For the case of the present sample, the statistical power reached is 0.52. (calculated with GPower 3.1).

During the recruitment process, written and audiovisual material was sent to the interested participants so they understood in advance what was going to happen in the experimental sessions. Once the participants agreed to take part in the study they came to the TimeLab at University of Manchester, where the experiment was conducted. To avoid tiredness and fatigue, the full set of assessments and experiments was divided in two sessions[2]. Session 1 included the ADOS second edition (only autistic participants), the Weschler Abbreviated Scale of Intelligence (WASI), the Glasgow Sensory Questionnaire (GSQ, Robertson and Simmons, 2013), the Developmental Coordination Disorder questionnaire (DCD, Kirby and Rosenblum, 2008), and two cognitive function tasks, CORSI of visuo-spatial working memory, and the Tower of London (TOL) as an indicator executive function (although restricted to mental planning first developed by Shallice, 1982). The normative data for CORSI shows a memory span of 6.2 (SD: 1.3) and a mean total score of 55.7 (SD: 20.3) (Kessel et al., 2000). The TOL on the other hand shows a normative score of 27.35 (SD: 4.04) (Michalec et al., 2017).

Session 2 involved three experiments and two questionnaires. The experiments were the Auditory Temporal Sensitivity Thresholds, Temporal and Pitch generalization, and the Dresden Breakfast task, and the questionnaires were the It's About Time (IAT - Barkley, 1998) questionnaire, and the Time Structure Questionnaire (TSQ – Bond and Feather, 1988). The rationale for including these questionnaires and assessments was to be able suggest possible explanations in case we find differences in the experiments of the current study. Thus, the relative performance of one group against the other is in this case more important than their absolute scores.

Thirty three autistic participants and matched controls by sex, age and IQ completed to a set of questionnaires (for details see Table 4.1) and three experimental tasks.

[2] This research is part of a larger study, so other measures were applied. Data collection was conducted by Dr Daniel Poole and Mr. Martin Casassus

Independent sample t-test revealed that higher scores in the GSQ in the autistic group in the whole questionnaires and in its subscales of hyper and hypo sensitivity. The autistic sample also showed higher scores in the DCD scale of dyspraxia, and significant differences in the AQ and all its subscales. Interestingly, the two scales assessing time perception and time management showed no differences. Equivalence between groups was also found in the tasks of executive function (Tower of London) and working memory (CORSI).

Table 4. 1: Questionnaires in the neurotypical and autistic groups

Test	ASC	TD	t	p
AGE	31.21 (8.16)	29.58 (7.48)	.899	0.372
FSIQ	117.55 (11.26)	117.67 (11.22)	-0.044	0.965
ADOS				
Full	9.5 (2.30)			
Communication	3.5 (1.27)			
Social interaction	5.94 (1.61)			
GSQ				
total	82.19 (22.82)	38.12(15.08)	9.055	<0.001
hyper-s	45.16 (13.15)	20.76 (9.68)	8.412	<0.001
hypo-s	37.03 (11.83)	18.94 (8.25)	7.055	<0.001
DCD	62.3 (17.06)	27.39 (13.94)	9.102	<0.001
AQ				
total	40.15 (5.5)	17.64 (9.49)	11.792	<0.001
social skills	8.21 (1.52)	2.93 (2.97)	8.753	<0.001
attention switching	9.15 (1.12)	4.53 (2.6)	9.009	<0.001
attention to detail	7.67 (2.04)	5 (2.15)	5.037	<0.001
communication	8.42 (1.73)	2.57 (2.14)	11.852	<0.001
imagination	6.55 (2.35)	2.3 (2.23)	7.360	<0.001
It's About Time	44.97 (7.9)	47.85 (6.19)	-1.648	0.105
Time Structure Q	108.44 (15.32)	105.24 (20.32)	0.717	0.476
Tower of London	25.3 (6.29)	28.03 (6.93)	-1.627	0.109
CORSI				
Total score	61.84 (24.68)	57.18 (22.3)	0.790	0.432
Mem span	5.58 (1.03)	5.47 (0.89)	0.461	0.647

GSQ: Glasgow Sensory Questionnaire; DCD: Developmental Coordination Disorder Questionnaire; AQ: Autism Quotient

A correlational analysis was conducted between all the questionnaires and the TOL and CORSI tasks (figure 4.1). The Bonferroni corrected p value was set at $\alpha = 0.002$.

Amongst the questionnaires there was a strong correlation between the AQ scores, the scores of the GSQ and the scores of the DCD ($p < 0.001$ in all of them). There was also a correlation between the scores of the executive function task (TOL) and the IQ scores ($p < 0.001$). None of the other correlation analyses reached statistical significance.

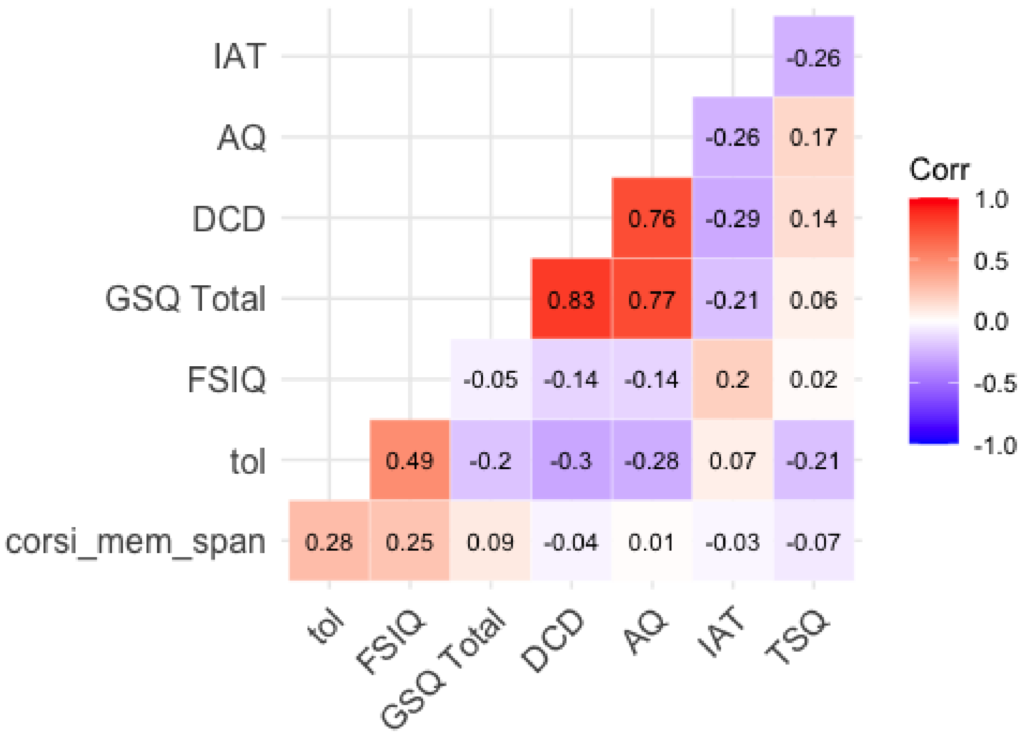

Figure 4. 1: Correlation between scales and questionnaires. IAT: It's about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London. Crosses are shown in those correlation values with $p > 0.002$ (Bonferroni corrected).

4.4. Experiment 1

4.4.1. Introduction

Time sensitivity refers to the ability to distinguish two durations as different (Rammsayer, 2010). So people with high sensitivity would be able to discriminate stimuli that others with low sensitivity perceive as equal. This basic notion of sensitivity to durations has led to a number of studies about differences in sensory modalities (Jones, Poliakoff and Wells, 2009), or stimuli characteristics such as filled and unfilled intervals (e.g. Rammsayer, 2010; Williams et al., 2018). Also, several methodologies have been employed in studying sensitivity to duration, from psychophysics to electrophysiological research. But despite the differences between modalities, stimuli, and methodology used, little is known about how large the difference between low and high time sensitivity has to be in order to impact behaviour in such way that can be characterised as impairment. This is one of the reasons that turned researcher's attention to psychopathology and neurodiverse conditions. Amongst these conditions, Autism Spectrum Condition (ASC) has had an increasing interest from the research community in the past 20 years. However, evidence is mixed and it remains unknown whether autistic individuals have a time sensitivity impairment, and if that is the case, how this impairment impacts other cognitive processes and the everyday life. Experiment 1, will explore possible differences in time sensitivity between autistic and neurotypical adults, and the possible relationship of this process to other cognitive abilities.

It has been argued that problems discriminating the duration of sounds may have an impact on functions such as speech comprehension, since, for example, some sounds may be perceived as overlapping. Four studies have attempted to characterise auditory sensitivity thresholds in ASC, with two studies finding comparable performance between groups (Mostofky et al. 2000; Jones et al. 2009) and two studies finding impairment in autism (Bathara et al., 2013; Kargas et al., 2015). Details of these studies are shown in the systematic review in Chapter 2 (Casassus et al., 2019), but it is worth mentioning that Bathara's study was a gap detection task instead of interval discrimination, so it may account for a different process (perception of continuity/discontinuity). All these studies worked with different versions of a PEST (Parameter Estimation by Sequential Testing) procedure, yet the evidence shows mixed results.

Temporal sensitivity thresholds are believed to be one of the most basic levels in time processing, where possible differences account for a sensorial level without the involvement of other high-order cognitive processes, such as memory or executive function. In order to characterise time perception abilities in autism (or other conditions), it is therefore important to know whether there is a difference in the input of temporal information before characterising other processes of more cognitive complexity. Although, the previous evidence is mixed, based on the results from the systematic review and the better powered studies (such as Jones et al., 2009), it is hypothesised that no differences will be found in the time sensitivity task. Additionally, this task has shown robustness, since it has been successfully applied to test and replicate findings such us the difference between modalities using the same procedure of the current study (e.g. Williams et al. 2019, replicated the findings from Jones et al., 2009).

4.4.2. Methods

4.4.2.1.Materials

Temporal sensitivity Thresholds: The task was presented using E-Prime software (Psychology Software Tools Inc.). Tones were reproduced in speakers located at the same distance and volume for all trials and participants. The task consisted in comparing of two tones at 400 Hz and spanning between 700ms and 1000ms, having the 700 ms stimulus as standard and with the comparisons starting at 1000 ms. For the responses, participants used an external number key pad to press number '1' or '2' according to their answer. All keys that were not used in the experiment were covered.

4.4.2.2.Procedure

The participants sat in a comfortable chair in front of the computer, using a chin rest in order to control the distance from the speakers. First the instructions were explained by the experimenter and then the participants read the instructions on the screen. After the instructions, examples of the tones were presented so the participant knew what to expect. Following the presentation of the stimuli, three practice trials were conducted and the experimenter asked if there were any questions before starting the experiment.

In each trial participants were asked to compare two tones and indicate which one was longer by pressing '1' (first tone was longer) or pressing '2' (second tone was longer). The initial difference in duration of the tones was 300ms, which was changed according to the participant's performance following an adaptive staircase procedure (Kaernbach, 1991) following a 3-down, 1-up rule. Each participant answered a total of 50 trials, and the threshold was calculated as an average of the last 20 trials (as done in Jones, Poliakoff and Wells, 2009). Additionally, participants completed the task twice, and the smaller estimated threshold was used for data analysis.

4.4.2.3.Data analysis

Treatment of outliers was conducted using 3*MAD (Median Absolute Deviation, Leys et al., 2013). After the removal of outliers, t-test analyses were conducted to compare the means of the temporal sensitivity thresholds between groups. Finally, the values of the thresholds were correlated to the questionnaires and cognitive assessments (Bonferroni corrected at $\alpha = 0.006$).

4.4.3. Results Experiment 1: Time sensitivity

Inspection of Figure 4.2 shows that the majority of participants in both samples had temporal sensitivity thresholds lower than 200 ms. Two participants from the autistic group had considerably higher thresholds. These two cases could have been treated as outliers (under MAD criterion), but since even with their inclusion the statistical analysis shows no differences, it was decided to not treat them as such. The autistic group had a mean threshold of 133.65 ms (SD = 102.12 ms), while the neurotypical group had a mean of 116.91 ms (SD = 71.34 ms). In order to determine whether autistic participants differed from general population in their ability to distinguish between two different durations a comparison between the temporal sensitivity thresholds was conducted. Since Shapiro-Wilks test showed a non-normal distribution, the groups were compared with Mann-Whitney U non-parametric test and showed no differences between the two groups ($W = 598$, $p = 0.497$, $r = 0.084$, $BF = 0.707$).

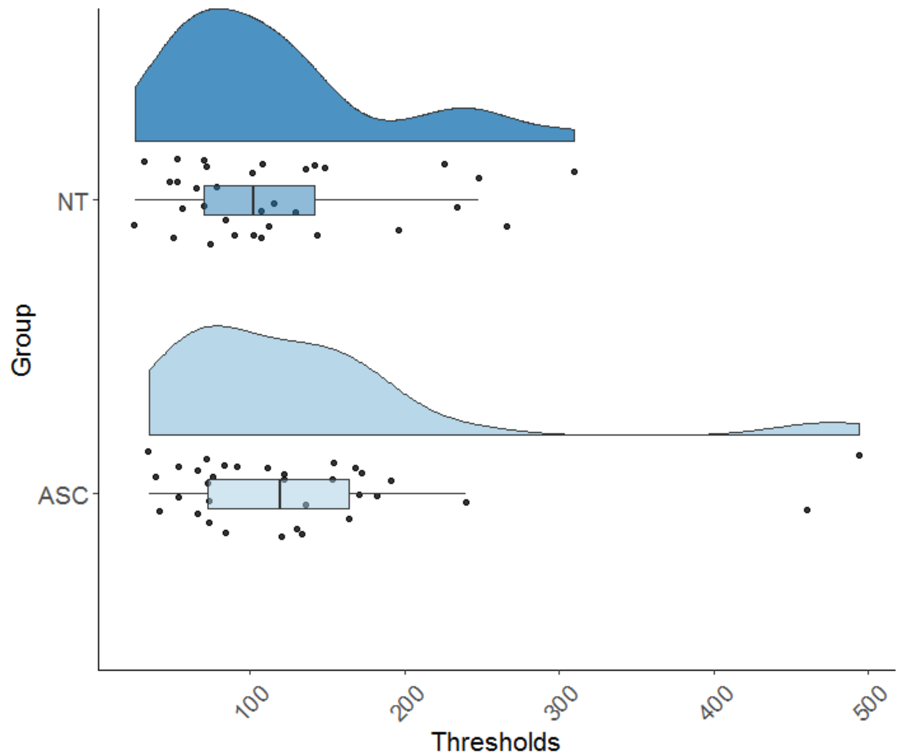

Figure 4. 2: Raincloud plot showing the boxplot and distribution of the autistic and neurotypical groups. Points are individual participant thresholds.

As can be seen in Figure 4.2, the autistic group has two participants with very high thresholds showing a performance clearly different from the rest of the group. For this reason, outlier treatment was conducted using MAD (see methods section) for the correlational analysis (highly susceptible to the effect of outliers. See Kim et al., 2015). From the outlier treatment of the data, three (2 ASC; 1 NT) participants were excluded from the following correlational analysis on temporal sensitivity thresholds.

As shown in Table 4.2, a correlational analysis showed that temporal sensitivity thresholds are not correlated with any of the questionnaires in the full sample (Bonferroni corrected to $\alpha = 0.006$). Additionally no correlations were found between thresholds and executive function or working memory. However in the case of the latter, there is a trend to significance where higher WM scores are associated with lower temporal sensitivity thresholds.

Table 4. 2: Correlation values of temporal thresholds to questionnaires and cognitive tasks.

	CORSI	TOL	FSIQ	GSQ	DCD	AQ	IAT	TSQ
Threshold	-0.32	-0.25	-0.06	-0.02	0.16	0.02	-0.14	-0.05
p value	0.015	0.090	0.266	0.818	0.299	0.773	0.36	0.65

P value Bonferroni corrected at 0.006
IAT: It's about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London.

4.4.4. Summary Experiment 1

Experiment 1 revealed comparable performance in the auditory temporal sensitivity thresholds between groups. Although there were two autistic individuals with very high thresholds, from the exploration of the raincloud plots and the statistical analysis it can be seen that both groups performed very similarly.

4.5. Experiment 2: Prospective Timing

The second experiment of this study explores possible differences between autistic and neurotypical population in their prospective time abilities. As was explained in the previous chapters, prospective time judgements are those made when you are aware that such judgement will be required. Typically this process is researched through comparison or estimation methodologies, and the SET model is one of the most accepted paradigms to explain this type of temporal judgement (See Introduction). Hence, impairment in prospective time abilities may reflect issues in one or more components of the SET model (i.e. pacemaker, memory, decision making). This experiment explores possible differences in prospective time between the same groups of Experiment 1. The results from Experiment 1 suggest that the input of the temporal information is not a factor of difference between groups, possible differences should be anchored in how the temporal information in processed in one of the three components of the SET model.

The current experiment used a Temporal Generalisation task to compare the performance between autistic and neurotypical individuals in prospective time abilities (see Chapter 3 and methods of this chapter for details). Previous research using a temporal generalisation task in autistic populations have shown less accuracy in both children (Brodeur et al. 2014) and adults (Falter et al., 2012). However, Brodeur's study worked with low-IQ autistic children, and an association between IQ and performance in temporal generalisation tasks has been shown (Wearden, Wearden and Rabbit, 2007). Using a version of the temporal generalisation task with a standard of 600 ms and probes at 300 and 900 ms, and the presentation of the standard in each trial, Lambrechts et al. (2018) found reduced accuracy in a group of 18 autistic adults and matched controls, and a trend for a difference in the pitch generalisation task (less accurate in ASC). They concluded that interval timing is not fully impaired in autism, but that autistic individuals may have problems remembering the standard as accurately as neurotypical individuals do. The current experiment used a temporal generalisation task to assess interval timing abilities and possible impairment in the SET model. Additionally, a pitch generalisation task (as in Lambretch's study) was used as a control task, so possible differences could be attributed to the perception of duration and not to a generalised perceptual impairment or to task-specific demands.

Since one of the findings from the systematic review was that increasing the involvement of other cognitive process increased the likelihood of observing differences between the autistic and neurotypical group, it is expected that different performance in the task will be anchored in the memory or decision making process of the SET model. If in fact there are differences between groups, the computer modelling should show differences in the index of memory variability (i.e. difficulty to remember the standard duration), and/or *the index* of threshold for decision making (i.e. a bias to conservative responses for example).

4.5.1. <u>Methods</u>

4.5.1.1.Participants

The same participants who took part in Experiment 1 participated in Experiment 2.

4.5.1.2.Materials

The same set of materials (computer, chin rest, speakers and number key pad) as in Experiment 1. The number key pad covered all numbers with the exception of numbers ‘8’ and ‘2’, which were replaced by ‘y’ and ‘n’ respectively for answering *Yes* or *No*. The temporal and pitch generalisation tasks were written and presented using Psychopy3 (Pierce et al., 2019). In the temporal generalisation task standards were tones of 500 Hz with durations of 400ms and 800ms in each version of the task. The comparison tones in both versions were a ratio of the standard at *0.25; *0.5; *0.75; *1.0; *1.0; *1.0; *1.25; *1.5; and *1.75, so the comparisons spanned between 100ms – 700ms in the 400ms version and between 200ms and 1400ms in the 800ms version. In the pitch generalisation task, the standards were set at 500 Hz and 1000 Hz, with comparisons at *0.94; *0.96; *0.98; *1.0; *1.0; *1.0; 1.02; *1.04; *1.06, so the comparisons spanned between 470 Hz – 530 Hz in the 500Hz version, and between 940 Hz – 1060 Hz in the 1000 Hz version. As in Experiment 1, the tones were set at the same volume for all the participants who were sat at the same distance from the screen and speakers.

4.5.1.3.Procedure

Once the participant was comfortably sat and had adjusted the chair in order to use the chin rest, the instructions were explained by the experimenter, who also informed the participant that they would be starting with the generalisation task. The order of whether a participant was starting with the temporal generalisation task or a pitch generalisation task was counterbalanced. Then instructions were also presented on the computer screen and the participant completed three practice trials before starting the task. The temporal generalisation task was organised in blocks. Each block started with the presentation of a standard tone that was presented 3 times, followed by the series of the nine comparisons presented in random order (i.e. nine trials). Each trial consisted of the presentation of a comparison followed by a question where the participant needed to answer if the duration of the comparison was the same ('yes'), or different ('no') compared with the standard. Each participant completed a total of six blocks per standard, and so a total of fifty-four trials per standard. The order of the blocks was fixed so all participants received the two standards interspersed. After the participant completed all the blocks of the temporal generalisation task, they had a short break and continued with the other generalisation task (i.e. if they had completed the pitch generalisation, they then completed the temporal generalisation afterwards).

4.5.1.4. Data analysis

The data analysis was conducted in first instance calculating an index of accuracy of the task. Accuracy was defined as the proportion of (True Positive + True Negatives) / 2 (Ogden et al. 2018). Comparisons of accuracy for the temporal and pitch generalisation tasks between the two groups were conducted using t-tests (for each version and the average of both versions). This index was also used to correlate the performance in the task with the scores of the questionnaires, cognitive assessments, and other indices from the tasks of the other experiments.

The analysis of the general performance of the task was conducted through a mixed ANOVA using the Comparison as within-subjects factor and the Group as between subjects factor to compare the general performance in the group. To confirm the possible involvement of the group factor as an explicative variable of the performance in the task, a Generalised Mixed Model Effect was conducted. Two models were compared with and without the inclusion of the Group belonging as a factor and Akaike Information Criterion (AIC) was used to check which model was a better fit. As an additional test, Bayesian Factors were estimated using the Bayesian Information Criterion (BIC) and interpreted following the guidance from Raftery (1995). Finally, a two-way repeated measures ANOVA using the version of the task (subtask condition. i.e. temporal and pitch generalisation) and the comparison as within-subjects factor was used to check superimposition (see Chapter 1) between the two versions of the tasks in each group separately.

Finally, as previous research has shown differences between levels of IQ (see Wearden, Wearden and Rabbitt, 1997) in temporal generalisation tasks, the full sample was split in quartiles from the IQ scores and comparisons between the levels was conducted using a Mixed ANOVA.

4.5.2. Results

4.5.2.1. Temporal generalisation

4.5.2.1.1. Accuracy

The analysis of the temporal generalisation task shows that both groups responded with high levels of accuracy. Table 4.3 shows that no differences by group were found in the 400 ms version of the task, but in the 800 ms version the autistic sample was less accurate than the neurotypical group. In the average between the two tasks no differences were found.

Table 4. 3: Accuracy in the temporal generalisation task

	ASC	NT	t	p	Cohen's *d*
400 ms	0.75 (0.1)	0.76 (0.13)	-0.341	0.346	0.09
800 ms	0.75 (0.1)	0.8 (0.7)	-2.518	0.015	0.125
Full task (average of subtasks)	0.75 (0.08)	0.78 (0.08)	-1.537	0.129	0.375

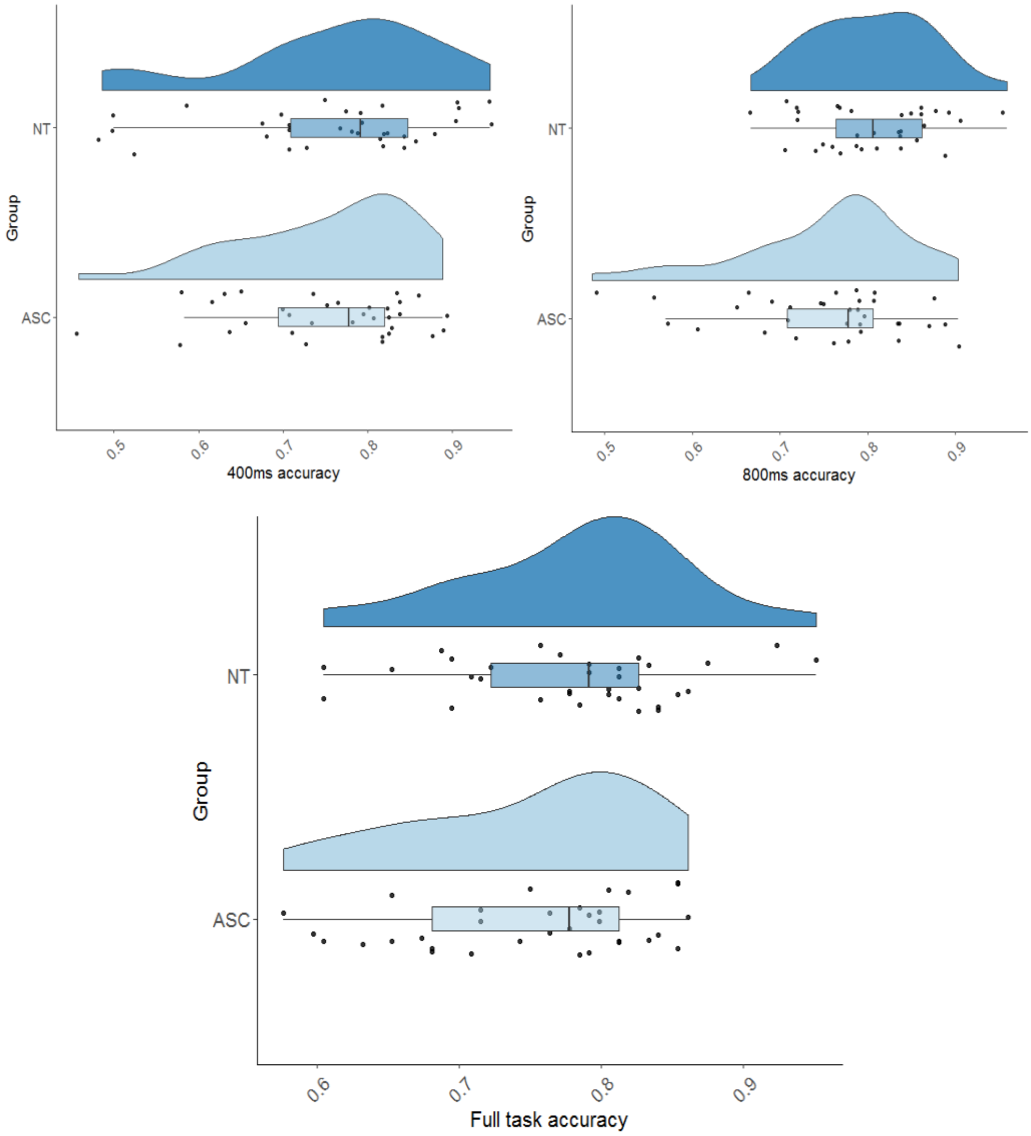

Figure 4. 3: Distribution of accuracy in the Temporal generalisation task. Left-upper panel shows the distribution of the accuracy in the 400 ms standard version; right-upper panel shows the accuracy in the 800 ms standard version; and, the lower panel depicts the average accuracy distribution of the two versions of the task.

The distribution of the accuracy scores of the participants in the two versions of the task shows that most of participants of both groups performed similiarly (Figure 4.3). The 400 ms version of the task shows that there are more participants from the neurotypical group having low levels of accuracy. Another observation to highlight in this descriptive level is that only the neurotypical group has participants with accuracy higher than 0.9.

A correlational analysis between the accuracy in the two versions of the task to the questionnaires and cognitive function tasks was conducted and analysed using a Bonferroni corrected α level of 0.006. The results show no correlations to any of the questionnaires or cognitive function tasks (all p > 0.006; Table 4.4). However, there are trends to significance in the correlation between the accuracy of the 800 ms version of the task to the executive function task, and the questionnaires AQ, GSQ, DCD and IAT.

Table 4. 4: Correlations between temporal generalisation accuracy to questionnaires and cognitive function task

	400 ms		**800 ms**	
	r	p	r	p
FSIQ	0.201	0.105	0.217	0.081
CORSI	0.129	0.309	0.06	0.638
TOL	0.229	0.072	0.292	0.021
AQ	-0.185	0.136	-0.244	0.048
GSQ	-0.069	0.589	-0.272	0.029
DCD	-0.181	0.147	-0.257	0.038
IAT	0.084	0.504	0.284	0.021
TSQ	-0.041	0.747	-0.128	0.311

IAT: It’s about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London.

4.5.2.1.2. Full Performance in the task

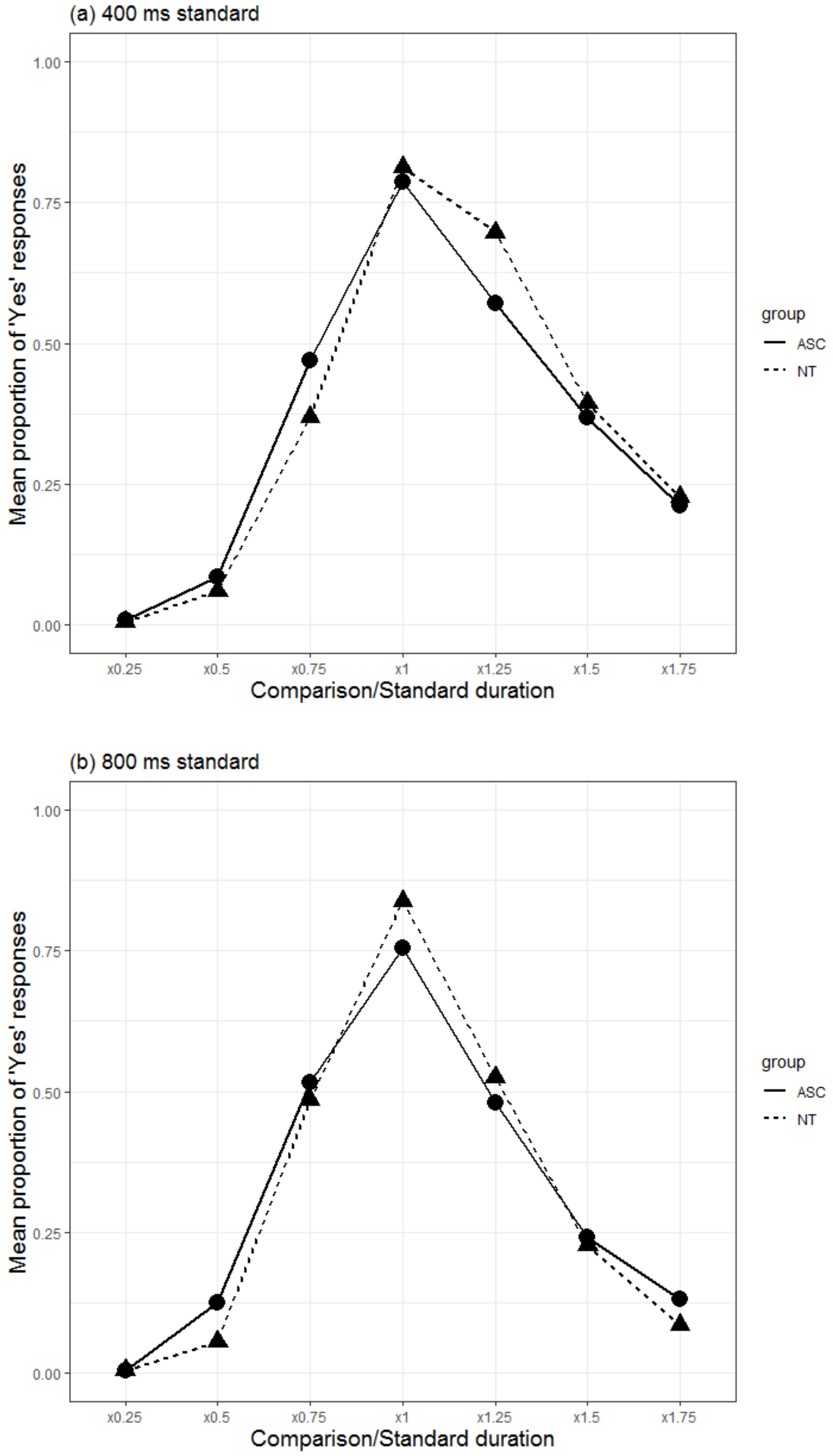

Figure 4. 4: Temporal generalisation gradients in the 400ms (upper panel) and 800ms (lower panel) versions of the task. The solid line represents the performance of autistic participants and the dashed line depicts the performance of neurotypicals. The X-axis shows presented comparison duration while the Y-axis shows the mean proportion of 'yes' responses.

General inspection of the upper panel of Figure 4.4 suggests no difference between groups in the performance on the 400 ms version of the task. A mixed ANOVA with Comparison duration as within-subjects factor and the Group as between-subjects factor, showed a significant effect of the Comparison, indicating that they were perceived as different ($F = 97.783$, $p < 0.001$), but no effect of Group ($F = 0.155$, $p = 0.694$), no interaction between Group * Comparison was observed ($F = 1.366$, $p = 0.227$). The same analysis was conducted in the 800 ms version of the task, showing an effect of the Comparison ($F = 115.76$, $p < 0.001$), but not effect of Group ($F = 0.051$, $p = 0.821$) and no interaction between Group * Comparison ($F = 1.004$, $p = 0.422$).

In order to confirm the null effect of group a GLMM was conducted contrasting a model with the inclusion of "group belonging" as predictor variable against a null-model (without its inclusion). In the 400ms version of the task, no differences were found between the models $\chi^2 = 0.083$, $p = 0.773$). Additionally, when comparing the AIC values the null-model had AIC = 16.847, while the model including the group was AIC = 18.764, indicating that the null-model leaves less information unexplained (a better fit). In order to estimate how strong the evidence in favour of the null hypothesis was, a Bayesian factor (BF) was estimated using the BIC values resulting in a BF = 20.625, which indicates that the evidence in favour of the null hypothesis is Strong according to Raftery (1995) criteria.

The GLMM analysis in the 800ms version of the task, showed no differences between the model including the group variable as predictor and the null-model ($\chi^2 = 0.024$, $p = 0.877$). The AIC comparison showed a smaller AIC value in the null-model (AIC = -68.274) than the model including the group (AIC = -66.298), indicating a better fit of the null model. Finally, the BF estimation analysis, showed that the evidence in favour of the null hypothesis was strong with BF = 21.232.

To check adherence to the scalar properties, *superimposition* between both versions of the task (400ms and 800ms) was tested in both groups (Figure 4.5). A two-way repeated measures ANOVAs using the subtask and the comparison as within factors showed no differences in neurotypicals (F = 2.155, p = 0.143) and no differences in autistic participants (F = 1.252, p = 0.264) between the two versions of the task. These results mean that both groups showed a good adjustment to scalar timing.

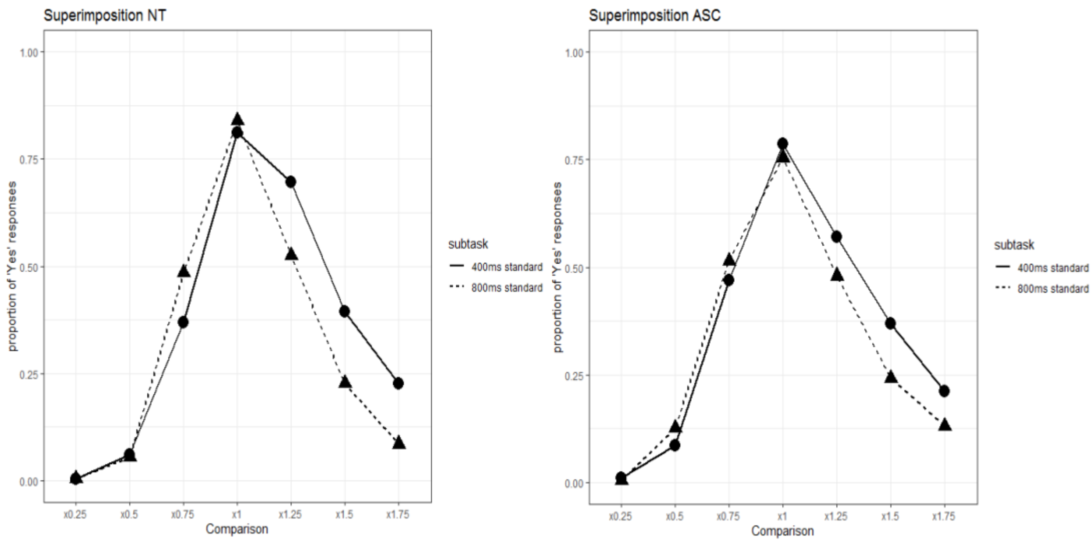

Figure 4. 5: Superimposition between the two versions of the task (400ms and 800ms) in neurotypical (left) and autistic (right) participants.

Finally we tested whether the IQ was affecting the performance in the task, so the IQ was split into four quartiles. One way ANOVA showed no differences in the accuracy of the task for the 400 ms standard (F = 1.207, p = 0.315) or the 800 ms version of the task (F = 0.932, p = 0.431). To test whether IQ affected the general performance in the task, a Mixed ANOVA was conducted with the comparison as within-subjects factor and the IQ quartile as between-subjects factor. The analysis showed a significant effect of the Comparison duration (F = 100.674, p < 0.001) no effect of the IQ level (F = 2.078, p = 0.102), and significant effect of Comparison * IQ (F = 1.644, p < 0.05). However, the post-hoc analysis did not show a significant effect in any of pairwise comparisons involving the IQ quartiles, and only a trend to better performance in high IQ in the 500 ms and 600 ms comparisons (p = 0.07, and p = 0.057 respectively). The same analysis in the 800ms standard version of the task showed an effect of the IQ Quartile (F = 3.079, p < 0.05), and an effect of Comparison (F = 115.459, p < 0.001), but no effect of Comparison * IQ Quartile (F = 0.536, p = 0.941). Post-hoc analysis showed no significant results for any of the pairwise comparison involving the IQ quartiles.

4.5.2.2.Pitch generalisation

4.5.2.2.1. Accuracy

In the analysis of the pitch generalisation task both groups performed well in the task, responding with a high level of accuracy. Table 4.5 shows that no differences by group were found in either the 500 Hz or the 800ms versions of the task. Additionally, the average between the two versions of the task also showed no differences.

Table 4. 5: Comparison of accuracy in the Pitch generalisation task

	ASC	NT	t	p	Cohen's *d*
500 Hz	0.77 (0.13)	0.76 (0.13)	0.535	0.595	0.08
1000 Hz	0.8 (0.13)	0.77 (0.12)	1.010	0.316	0.24
Full task (average of subtasks)	0.79 (0.12)	0.76 (0.11)	0.838	0.404	0.26

A correlational analysis showed no correlation between the 500 Hz subtask and all the questionnaires and cognitive function tasks (p value Bonferroni corrected at 0.006). The only exception was a significant correlation with the IQ scores, where better accuracy was related to higher IQ (r = 0.35, $p < 0.006$). However, this correlation was only a trend to significance in the 1000 Hz version of the task as shown in table 4.6.

Table 4. 6: Correlations between pitch generalisation accuracy to questionnaires and cognitive function tasks

	500 Hz		1000 Hz	
	r	p	r	p
FSIQ	0.361	0.003	0.275	0.026
CORSI	0.128	0.315	0.208	0.099
TOL	0.26	0.045	0.102	0.43
AQ	0.015	0.904	0.143	0.251
GSQ	-0.057	0.653	0.094	0.458
DCD	-0.056	0.657	0.058	0.646
IAT	-0.044	0.727	-0.075	0.549
TSQ	0.076	0.547	0.081	0.52

IAT: It's about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London.

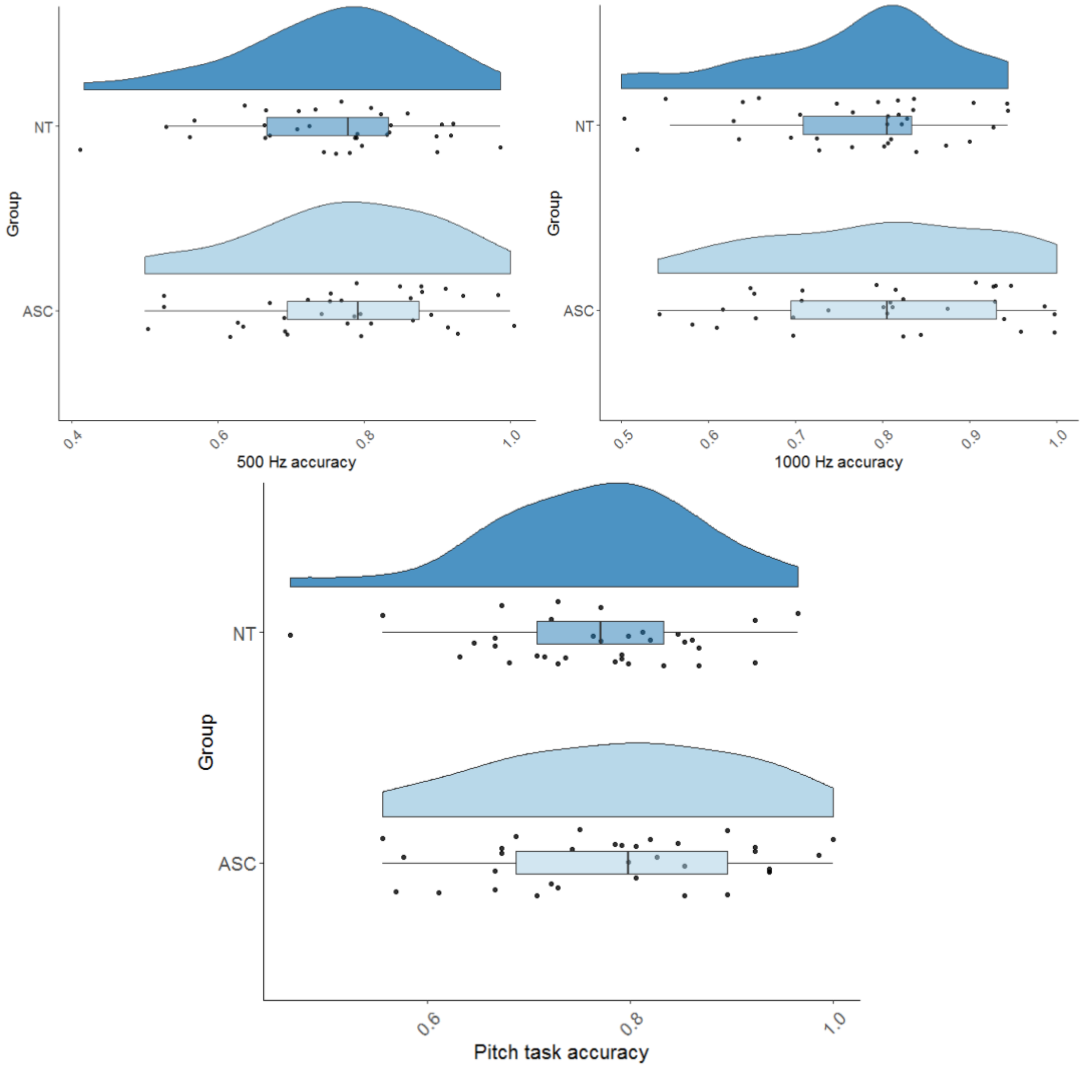

Figure 4. 6: Raincloud plots for the distribution of both groups in the pitch generalization task. The left-upper panel shows the distribution in the 500 Hz version of the task; the right-upper panel shows the distribution in the 1000 Hz upper panel; the lower panel shows the distribution resulting from the average of both versions of the task as a general pitch generalisation accuracy distribution.

4.5.2.2.2. Full Performance in the task

Visual inspection of general performance in both versions of the pitch generalisation task suggests no differences between groups (Figure 4.6), although there seems to be a slight trend towards a more conservative pattern of response in the autistic group.

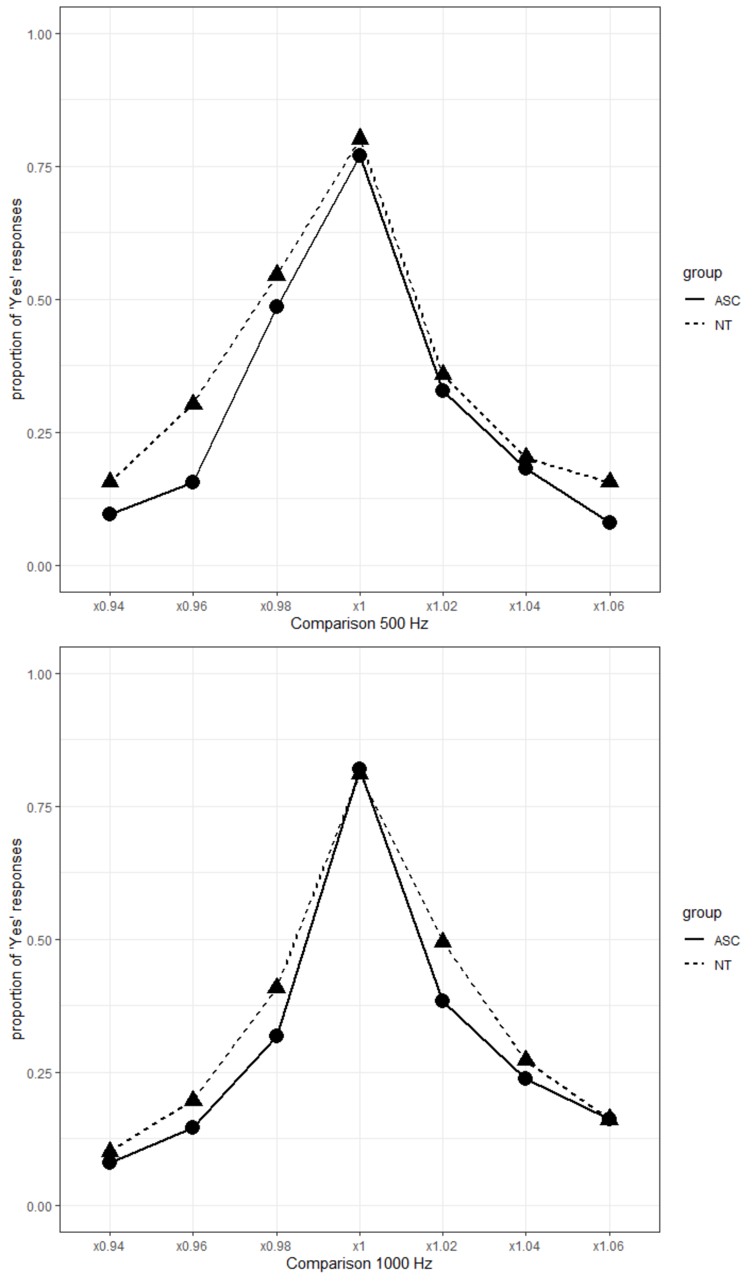

Figure 4. 7: Pitch generalisation gradients in autistic and neurotypical participants. Upper panel shows the 500 Hz version of the task, while the lower panel depicts the 1000 Hz version.

A mixed ANOVA using the Comparison Pitch as within-subjects factor and the Group as between- subjects factor, revealed an effect of both the Comparison (F = 96.957, p < 0.001) and Group (F = 8.378, p < 0.01) in the 500 Hz version of the task, basically driven by the more conservative pattern of response in the autistic group. However, the analysis showed no effect of the interaction between Group * Comparison. The analysis of the 1000 Hz version of the task showed similar effect, with a significant effect of the Comparison ($F = 75.529$, $p < 0.001$) and Group ($F = 0.945$, $p < 0.05$), but no effect from the interaction Group * Comparison ($F = 0.634$, $p = 0.703$). These results suggest that the condition of belonging to the autistic or neurotypical group affects the performance in the pitch generalisation task, with the autistic group showing slightly better performance.

To explore the previous analysis more deeply, the same GLMM used in the temporal generalisation task was used in the pitch generalisation. In the 500 Hz version of the task, no differences were found between a model including group as predictor against a null-model ($\chi^2 = 3.653$, $p = 0.056$). However, a comparison from the AIC values showed that the model including the group variable was a slightly better fit (AIC = -62.428) than the null-model (-60.775). The BF estimation analysis showed BF = 3.46, which indicates positive evidence in support of the null hypothesis. The 1000 Hz version of the task the GLMM showed no differences between the null-model and the model including the group as predictor ($\chi^2 = 1.647$, $p = 0.199$). The model comparison through AIC showed a slightly better fit of the null-model (AIC = -48.108) than the model with the variable group included (AIC = -47.756), indicating that the null model leave less *information* unexplained. Finally, the BF estimation showed a BF = 9.4, which means that the evidence supporting the null hypothesis is positive. From all these results together it can be inferred that there is not enough evidence to support that the variable group significantly affects the performance in the pitch generalisation task.

Superimposition was also tested in the pitch generalisation task. As with the temporal generalisation task, a two way repeated measures ANOVA with the Comparison and Subtask as within subject factors. The results in the neurotypical group indicate that both versions of the task superimpose ($F = 0.132$, $p = 0.717$).

This results were the same in the autistic group (F = 0.061, p = 0.805) were no differences between the two versions of the task were found either (Figure 4.8).

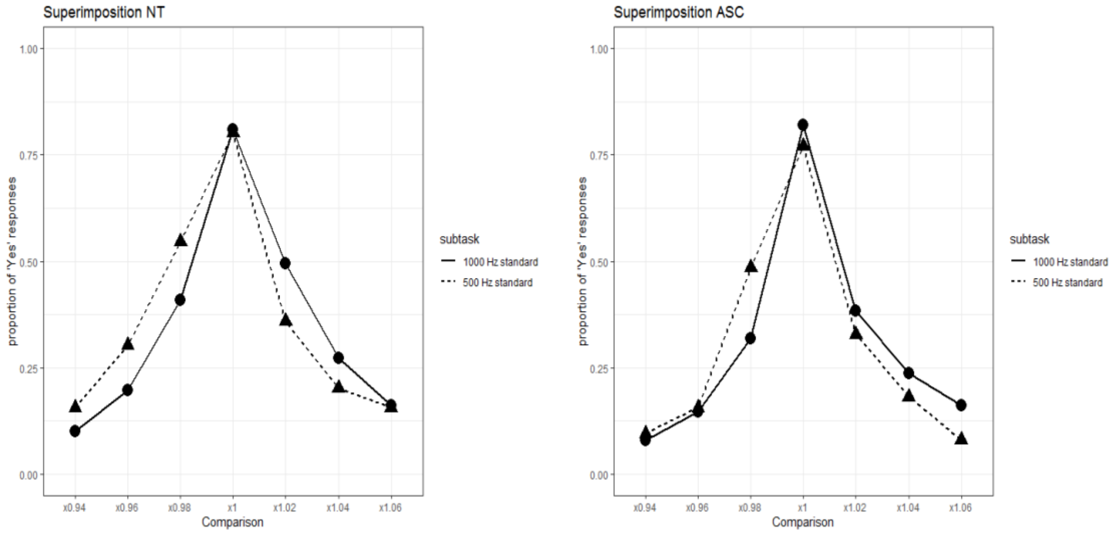

Figure 4. 8: Superimposition of gradients in the neurotypical (left panel) and autistic (right panel) groups.

To analysis of the effect of IQ in the pitch generalisation task was conducted as in the temporal generalisation task. A One-way ANOVA using the quartiles of IQ as factor showed no effect of IQ in the accuracy of 500 Hz version of the task (F = 2.378, p = 0.08) or the 1000 Hz version (F = 0.736, p = 0.535). A mixed ANOVA with the comparison duration as within subject factor and the IQ quartiles as between subject factor showed an effect of the pitch comparison (F = 77.083, p < 0.001), but no effect of the IQ quartile (F = 2.241, p = 0.083) or the interaction quartile * pitch comparison (F = 1.108, p = 0.340). On the other side, the analysis of the 1000 Hz version of the task showed an effect of the pitch comparison (F = 75.688, p < 0.001), but a significant effect of the IQ quartile (F = 4.617, p < 0.01), driven by a difference between the Low IQ group and the Mid-low IQ group (p < 0.001). However, this effect disappeared in the interaction IQ quartile * Pitch comparison (F = 0.492, p = 0.961).

4.5.3. Summary Temporal and Pitch generalisation tasks

As a whole, the second Experiment suggests no differences in prospective time abilities between autistic individuals and neurotypicals as measured with a temporal generalisation task. However, there was a difference in the accuracy index in the 800 ms standard, which was driven by the presence of outliers only in the autistic group (outliers were present in both groups in the 400ms standard), but this effect of the group disappeared in the average accuracy of the 400 and 800 ms standards. In the analysis of the general performance in the task, no differences were found in any of the between group conditions. Additionally, the GLMM showed that including the group condition in the statistical model resulted in a worse prediction of the performance in the task, which was also supported by the AIC comparison. Moreover Bayes factors show strong evidence for the null hypothesis. Finally, both groups showed comparable adjustment to the properties of scalar timing tested by superimposition. Altogether, the results in the temporal generalisation task do not support the idea of impair prospective time abilities in autism.

In the Pitch generalisation task the results are less strong in showing equality between groups. There were no differences in the accuracy of pitch generalisation, but the mixed ANOVA showed that the group condition was a factor, but only on its own. The effect of the group condition disappeared in the interaction group * comparison, which is a better indicator of the general performance in the task (because compares the groups at each comparison). The GLMM showed no differences between groups (although there was a trend), and the AIC comparison showed that including the group condition in the predictive model resulted in a worse model. The fact that the results in the pitch generalisation task were less strong that in the pitch than temporal generalisation task, was confirmed by Bayes factors which found only *positive* evidence in favour of the null hypothesis (instead of strong evidence as happened in the temporal generalisation task).

In summary, the results suggest a conserved ability in autistic individuals to encode and retrieve the temporal characteristics of auditory stimuli, and a trend to better performance in the case of the pitch. Finally, no correlations were found between the performance in the task and the questionnaires or cognitive function tasks, although there are trends in the 800 ms standard of the temporal generalisation task. The absence of correlation between the working memory task and the performance in the temporal and pitch generalisation tasks may indicate that working memory for duration and pitch is independent from spatial working memory (which is what was tested through CORSI).

4.6. Experiment 3: Dresden Breakfast Task – M

Experiment 1 showed no problems time perception in a sensorial level, and Experiment 2 showed no differences in how the groups perceive durations prospectively. So, it is possible that the problems with time referred by autistic individuals and their relatives are related to other more complex behaviours and management of time in everyday life situations. Therefore, Experiment 3 was intended to explore time perception abilities in autistic individuals in complex situations and tasks, where the involvement of other cognitive processes such as executive function, are strongly involved.

Prospective memory is the ability to behave according to pre-planned actions at a certain moment (Park et al., 1997). So this is a type of memory for activities to be conducted in the future, like remembering to stop an ongoing activity (e.g. reading a book) because you will receive a visit, or attending to an appointment at a certain time (Einstein and McDaniel, 1990). So, this type of memory involves the retrieval of information from long-term memory (Park et al. 1997), and to give an appropriate response in response to a specific cue, which can be external/contextual or a self-initiated inside process (Einstein and McDaniel, 1990). According to the type of cue that should trigger a specific action in the future, prospective memory has been divided in time-based (TBPM) or event-based prospective memory (EBPM) (see Chapter 2). It has been proposed that TBPM relies on internal processes associated to monitoring time internally (Henry et al., 2004). So, prospective memory is a cognitive process that involves several cognitive resources, including working memory, long-term memory (encoding, storing, and retrieval), and executive function (planning, monitoring, attentional switching, task initiation, and inhibition). The current experiment will test TBPM and EBPM abilities in the same sample as in the previous two experiments.

As was presented in the systematic review (Chapter 2), previous research has shown consistent findings of impairment of TBPM abilities in autism in both children (Williams et al., 2013; Henry et al., 2014) and adults (Altgassen et al., 2012; Kretschmer et al. 2014; Williams et al., 2014). However, there are some methodological considerations that invite careful interpretation of this consistency between studies, at least in what refers to time perception processes. In the studies with adults, two of the three studies (Altgassen et al., 2012; Kretschmer et al. 2014) found differences in both TBPM and EBPM, so it is possible that the samples had a broad prospective memory impairment more than a specific issue related to durations. But even more importantly, all these studies involved the presence of a clock (or time aid of some sort) that could be accessed by the participants under request (e.g. pressing a key). So this internal monitoring process (as defined by

Henry et al., 2004) was mixed with an external clue that allowed the participants to re-calibrate their temporal productions, and so, adding another component to the task. This experiment is the first to test TBPM in autism without the presence of time aids.

Given the evidence of the problems autistic individuals have in tasks with high involvement of executive function resources, and the previous evidence with this task consistently showing differences, it is expected that performance between groups will be different. More specifically, it is expected that autistic individuals will fail the task in a higher proportion (more autistic individuals failing to complete the task), and that they will be less accurate when producing the given durations.

4.6.1. Methods

4.6.1.1. Participants

Participants were the same as Experiments 1 and 2.

4.6.1.2. Materials

The task was conducted in the same lab as the psychophysics tasks. After a break from the previous experiment, the room was modified and a little table for two people was deployed in the room. A *go-pro Hero Session* camera was set in a corner of the room to record all the experimental session. The materials for the breakfast task were a kitchen set for four individuals, a teapot, a fridge, a toaster, a table cloth, and a kettle. For safety reasons the toaster was not plugged in, and the noise of a toaster was reproduced through speakers. Also, the kettle was set on 80 degrees instead of 100 degrees. Finally a sheet with the instructions was delivered to the participant. Since a subtask involved the manipulation of butter, an alternative of vegan jam was used under request. No time aids of any kind were available for the participants.

4.6.1.3. Procedure

The Dresden Breakfast Task (Altgassen et al., 2012) is an ecological task that measures Time-Based Prospective Memory (TBPM) and Event-Based Prospective Memory (EBPM) where typically the participant needs to prepare breakfast for four people, following a set of rules. Because of space restrictions in the lab and safety measures (e.g. decrease risks of fallings), this version was adapted to prepare breakfast for only two individuals. The instruction read as follow:

In the following task you will need to prepare breakfast for 2 people: you and me. You will have 7 minutes to complete the task at which time the guest will arrive (I will return to the room).

Area number 1 will be our kitchen and Area number 2 will be our dining table (the experimenter showed the areas).

This is a picture of how the table should be set, and two extra rules.

1. You need to take the butter out of the fridge 6 minutes before the guest arrives.

2. You need to brew the tea for exactly 3 minutes. Put the lid back on the teapot while it is brewing. Show that the 3 minutes has passed by serving the tea in the two mugs.

Once everything is ready, take a seat in the breakfast table and wait for me.

Please, be as accurate as you can.

Now, check the materials and plan your task. Please write your plan on this paper

The experiment started after the experimenter gave the instruction sheet to the participant. The experimenter then read aloud the instructions, showing the materials when they were referred in the instructions. Once the instructions were clear and the experimenter had answered any questions, the experimenter showed how to prepare the tea and how to use the kettle. The participant then had a few minutes to plan the task. Once the participant was ready, they received the two instructions of the EBPM tasks they had to remember (so they did not include them in the plan). Once everything was ready, the experimenter left the room. While the experimenter was outside the room they observed what was happening through a phone connected to the go-pro camera. A beep through the speakers was the initial cue to start the task, and the session ended when the experimenter returned to the room 7 minutes after the beep.

Time-based Prospective Memory (TBPM): This cognitive process was assessed with two subtasks. In the first one the participant needed to wait 1-minute from the beginning of the task (beep) to take the butter from the fridge. The second subtask was to brew the tea for 3-minutes. An accuracy index was calculated for each subtask by ((Target – Produced duration) / Target). Additionally, an absolute accuracy was also calculated by ((|Target – Produced duration|) / Target). The rationale of using both measures is that accuracy gives a measure that takes into account whether the produced durations are underproductions or overproductions, but the absolute accuracy only takes into account how near the target they were, independently of the direction. Additionally, a score of achievement was used in order to have a common index with previous studies. One point was assigned if the participant completed the task with 30-seconds of the target time, and 0 points if they did not.

Event-based Prospective Memory: These were two rules the participant needed to remember and they could not take notes about them. The first subtask was to start brewing the tea immediately after the water boiled (water-subtask). The second subtask was to put the toast on the table when they heard the noise of the toaster being ready (played through the speakers) (toaster-subtask). Only the achievement criterion was used with the same scoring system as the TBPM tasks (one point was assigned if the participant completed the task with 30-seconds of the target time, and 0 points if they did not.).

For the coding process, a coding protocol was elaborated (Appendix B). This consisted in watching each participant's video recording and marking the times at which they started and completed the actions of the TBPM and EBPM tasks. For example, in the butter subtask the temporal production of the participants was coded from the beep indicating the beginning of the task, until the moment the participants touched the fridge to take out the butter. The main researcher (MC) coded all the videos. Additionally, as a measure to control possible bias or typos in the coding, three undergraduate students were trained in the coding protocol in 5 sessions coding pilot data. Each student received 40 videos randomly assigned to code, and they were blind about whether a video was from the autistic or the control group. Then the main researcher compared his codes with the ones coded by the students.

Differences in the coding were solved by recoding the full record and not only the point of disagreement.

After the task, a short interview was conducted to give feedback and manage any possible distress. This interview was also used as a distractor to include a retrospective time question. In the middle of the interview the experimenter asked: “As accurately as you can, how long do you think has passed since I sat in this chair”

When participants answered range (e.g. 4-5 minutes) they were asked to choose only one answer.

4.6.1.4.Data Analysis

For the analysis of the data t-test were conducted to compare the performance of the groups in each TBPM task using the raw durations they produced and the accuracy indices. An independent groups proportion comparison was used to compare the achievement rate of the tasks. Additionally, a mixed ANOVA was analysed using the Subtask of the TBPM task as within-subjects factor, and the Group as between-subjects factor. Finally, correlations were used to check possible relationships between the task and the questionnaires and cognitive assessments.

Retrospective time data was analysed as in Chapter 3.

Finally, the full sample was divided in two groups from percentile 75 of the accuracy values of the TBPM task. Then a description of the 25% of worse performance was conducted using the different scales from the general characterisation of the sample and their performance in the other experiments.

4.6.2. Results

4.6.2.1. Time Based Prospective Memory

The performance butter subtask of the TBPM task was compared between the autistic and neurotypical groups. From the full sample, 33 autistic participants and 31 neurotypicals completed the task. Two neurotypical participants failed the task because they forgot about the butter instruction and did not follow the instruction sheet they had with them, so they were excluded from analysis. From the inspection of the raincloud plots in Figure 4.9 showing the distribution of performance of both groups in the butter and tea subtasks, it can be seen that the production of the one-minute duration in the butter subtask was very similar between both groups, although in the autistic group there are five participants that have deviant performance. On the other hand, the 3-minutes production in the tea brewing subtask showed individuals with deviant performance in both groups, although with a higher frequency in the autistic participants, where few participants markedly under-produced the target duration, which is a type of performance that was not present in the group of neurotypicals.

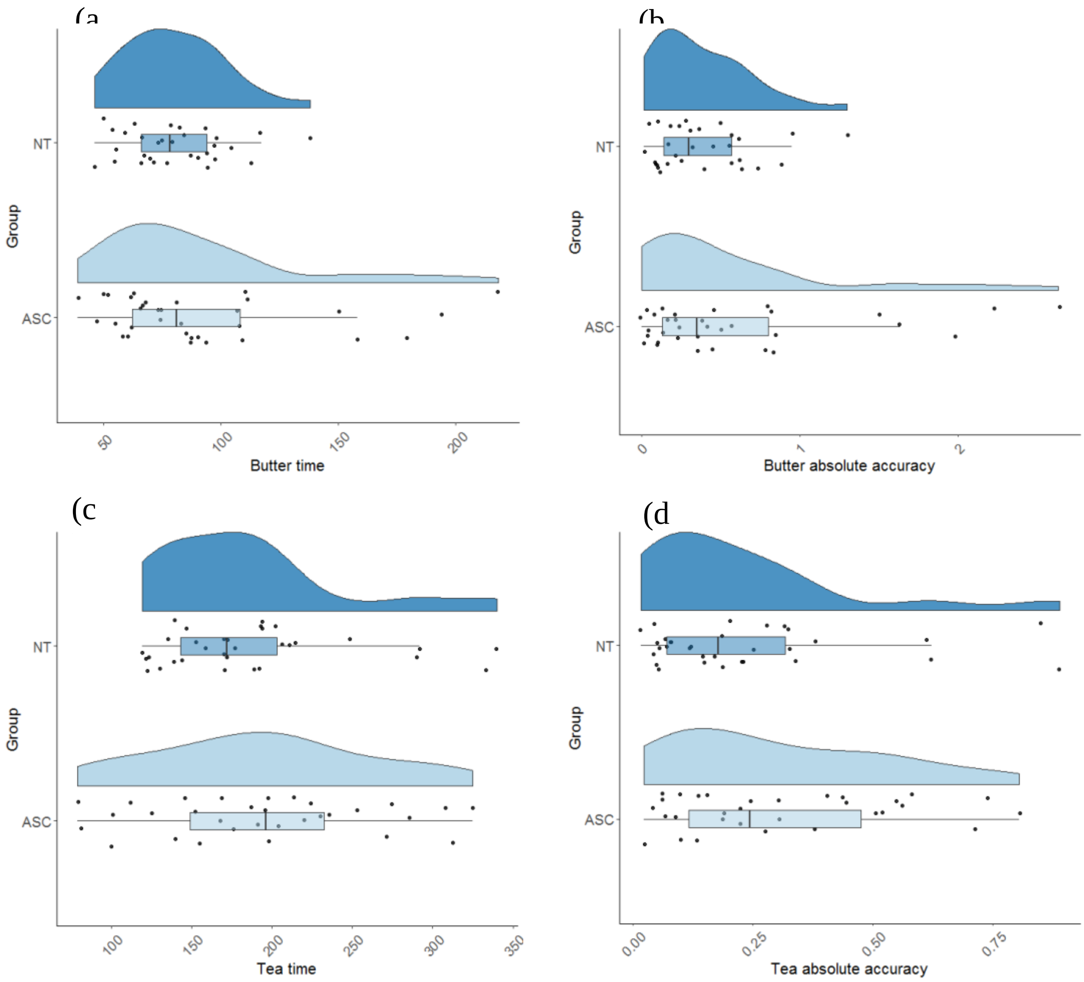

Figure 4. 9: Distribution of duration production in the butter task (target 1min). Right panel shows the raw duration produced by the participants of both groups, and left panel the absolute accuracy of that produced duration.

T-test analyses showed no significant differences between groups in either the raw time used in the task, accuracy, or absolute accuracy (Table 4.7). In order to be able to compare these results to previous research, a rate of achievement was also compared, finding no differences between groups.

Table 4. 7: Time-based prospective memory tasks

		ASC	NT	t	p	Cohen's *d*	BF(r)
Butter	Raw time	91.48 (43.56)	80.39 (21.27)	1.307	0.198	0.17	0.511
	Accuracy	-0.52 (0.73)	-0.34 (0.35)	-1.307	0.198	0.17	1.359
	Absolute accuracy	0.58 (0.68)	0.38 (0.3)	1.542	0.13	0.20	1.359
	Achievement rate	0.85	0.91	0.502*	0.479		
Tea	Raw time	194.52 (67.98)	186.28 (58.68)	0.514	0.609	0.07	0.288
	Accuracy	-0.08 (0.38)	-0.03 (0.33)	-0.514	0.609	0.07	0.288
	Absolute accuracy	0.31 (0.23)	0.24 (0.22)	1.293	0.201	0.16	0.519
	Achievement rate	0.58	0.78	3.137*	0.08		

*Chi^2 value resulting from a proportion comparison instead of t-score

In order to analyse the TBPM tasks as a unified process, a Mixed ANOVA was conducted using the Group as between-subjects factor and the accuracy in each subtask as within-subjects factor. The results showed a main effect of the Subtask ($F = 19.755$, $p < 0.001$) with the tea subtask being more accurate than the butter subtask (-0.06 and -0.44 respectively). There was no Group ($F = 1.858$, $p = 0.175$) or Group*Subtask interaction ($F = 0.670$, $p = 0.415$).

Given that the two TBPM task were correlated ($r = 0.32$, $p < 0.05$), a total score of TBPM abilities was calculated as an average of the absolute accuracy in each subtask, resulting in a mean of 0.47 (SD: 0.47) for the autistic group and a mean of 0.31 (SD: 0.22) for the neurotypical group. A t-test analysis revealed no differences between group ($t = 1.818$, $p = 0.076$). Although this analysis shows a trend to significance, from Figure 4.10 it can be inferred that that trend is mainly because of the presence of outliers in the autistic group. Finally no correlation was found between TBPM accuracy and any of the questionnaires or cognitive function tasks (Table 4.8).

Table 4. 8: Correlation between TBPM accuracy and questionnaires

	FSIQ	GSQ	DCD	AQ	TSQ	IAT	TOL	CORSI
r	-0.017	0.116	0.011	0.185	-0.015	-0.041	-0.028	-0.114
p value	0.89	0.359	0.933	0.135	0.905	0.738	0.827	0.368

IAT: It's about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London.

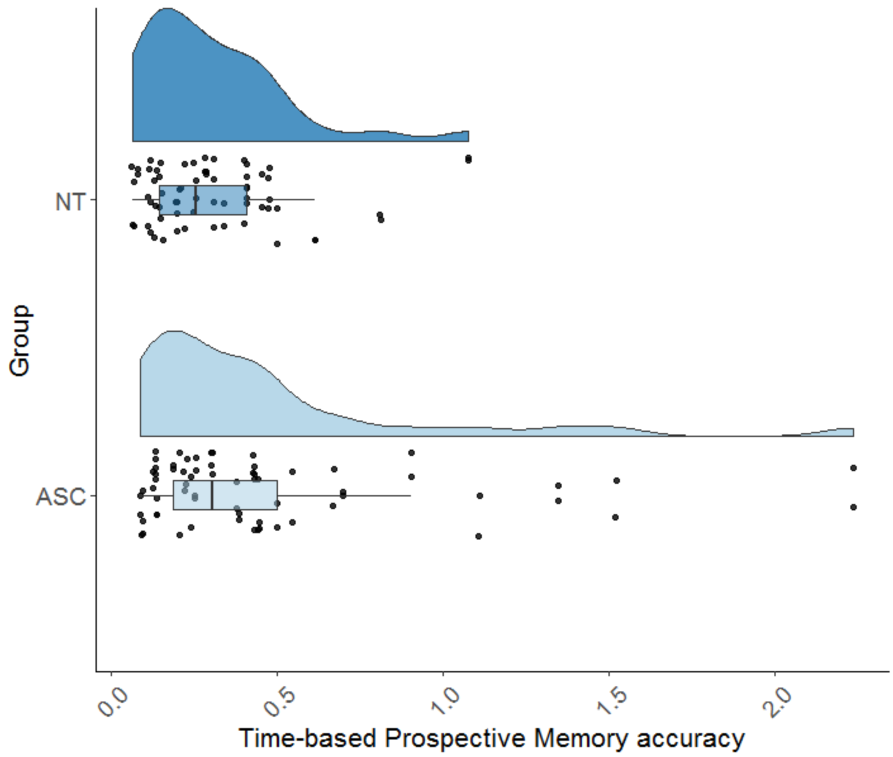

Figure 4. 10: Time based prospective memory accuracy in neurotypical and autistic groups. There are no statistical differences between groups. Both groups have presence of outliers but these are more frequent and more extreme in the autistic group.

4.6.2.2.Event based prospective memory

The water-subtask analysis involved 33 autistic participants and 31 neurotypicals. In the neurotypical group, the two exclusions were because they boiled the water twice and served the water before it boiled the second time. The toaster-subtask analysis included 33 autistic and 29 neurotypical participants. Four neurotypical participants were excluded because the noise of the toaster was not audible during the experimental session. The water task was achieved by 79% of the autistic participants and 94% of the neurotypicals, but no statistical difference were reached (Chi2 = 2.88, p = 0.089). The toaster-task was successfully achieved by 88% of the autistic participants and 100% of the neurotypical participants, showing no statistical differences between groups (Chi2 = 3.76, p = 0.053). The final scored of EBPM was compared by a Wilcoxon test, and revealed no differences between groups either (W = 495, p = 0.423).

Correlational analysis using Spearman Rho showed no correlations between the score of EBPM and any of the cognitive tasks or questionnaires (all $p > 0.05$), with the exception of the Time Structure Questionnaire (TSQ) which scores were negatively correlated ($r = -0.34$, $p < 0.006$) (Bonferroni corrected to $\alpha = 0.006$), indicating that poorer performance was associated to a better structure of time (although this may be spurious, and the correlation value is rather weak). Finally, no correlation was found between the TBPM task and the EBPM task (r = 0.086, p = 0.493).

Table 4. 9: Correlation between EBPM scores and questionnaires

	FSIQ	GSQ	DCD	AQ	TSQ	IAT	TOL	CORSI
Spearman's Rho	0.101	-0.014	-0.192	-0.136	-0.339	0.161	0.004	-0.007
p value	0.419	0.908	0.124	0.275	0.006	0.197	0.975	0.959

IAT: It’s about time; AQ: Autism Questionnaire; DCD: Developmental Coordination Disorder questionnaire; GSQ: Glasgow Sensory Questionnaire; FSIQ: Intellectual coefficient; TOL: tower of London.

4.6.2.3.Retrospective time

The retrospective time question was answered by 29 and 27 participants in the autistic and neurotypical groups respectively. From these, one autistic participant was excluded because the judgement was required late in the interview, so the target time to be judged was considerably longer than the others (its target time was 1095 seconds and the mean of the rest of the group was 228.28 seconds). A general accuracy index was calculated for the full sample showing a value of 0.49 suggesting a moderate level of accuracy. Also, a correlation was found between target and estimation time ($r = 0.34$, $p < 0.01$), which suggests that as whole participants showed some adjustment to the scalar properties (shorter durations judged shorter than longer durations). Table 4.10 shows that there were no statistical differences between groups on their level of accuracy (absolute accuracy), with the autistic group showing a trend to be more accurate. However, as shown in Figure 4.11, this apparent trend might be grounded by two participants in the neurotypical group who were conspicuously inaccurate (outliers).

Table 4. 10: Retrospective timing in autistic and neurotypical individuals

Group	Target	Estimation	Accuracy	Absolute accuracy
ASC	228.28 (86.49)	222.59 (122.2)	0 (0.47)	0.35 (0.3)
NT	169.59 (64.4)	182.78 (136.48)	-0.19 (1.13)	0.65 (0.93)
t	2.893	1.147	0.821	-1.594
p	0.006	0.257	0.418	0.121
Cohen's d	0.39	0.15	0.12	0.24

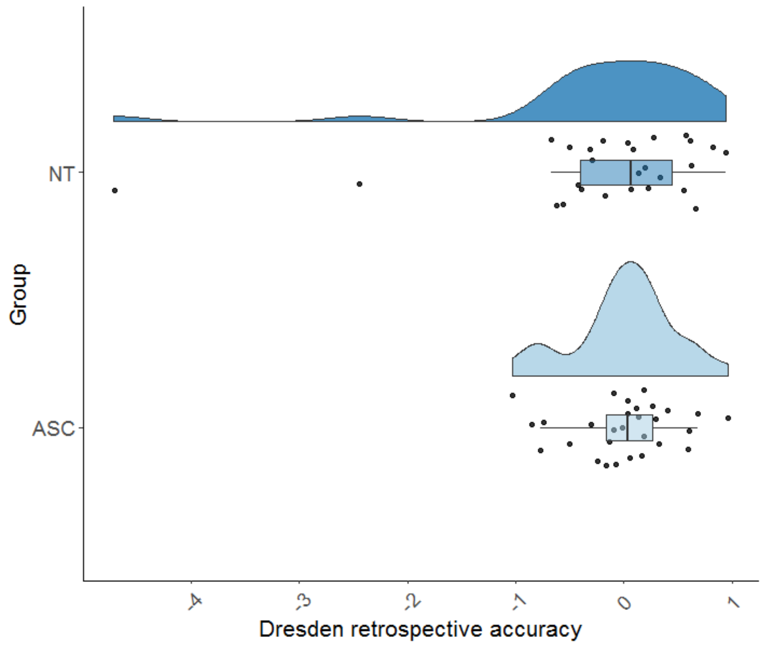

Figure 4. 11: Raincloud plots for retrospective task accuracy.

A correlational analysis between the retrospective judgement and the TBPT task showed no correlation for both accuracy indices (r = 144, p = 0.289; and, r = 0.163, p = 0.249 respectively. No correlation was found either between the retrospective judgement absolute accuracy and working memory (r = -0.151, p = 0.277), or between retrospective absolute accuracy and executive function (r = 0.142, p = 0.315), suggesting an independence of the accuracy in the retrospective judgements from these two cognitive processes. However, a significant correlation was found in the full sample between absolute accuracy of retrospective judgements and IQ (r = -0.388, p < 0.01), which indicates that individuals with higher IQ scores tend to be more accurate on their retrospective judgements (p values Bonferroni corrected at 0.01).

4.6.2.4.Characterisation of outlying Time Based Prospective Memory

In order to explore the characteristics of individuals with atypical TBPM abilities, 25% of the participants with higher scores of absolute accuracy (less accurate) were selected as a subsample. This cut-off point was selected (instead of using other options such as SD) because of the skewed distribution of the sample. From the full sample, 16 participants showed more inaccurate performance in TBPM (Figure 4.12). The individual characterisation of the atypical performance group shows that 9 of these participants were autistic individuals and 7 were neurotypicals.

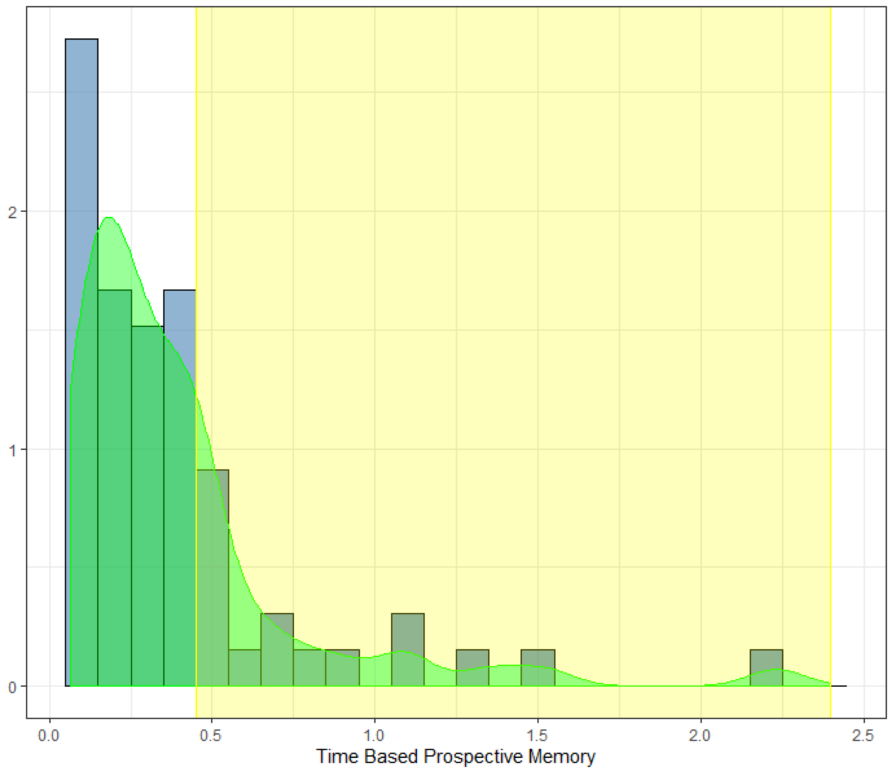

Figure 4. 12: Distribution of scores of absolute accuracy in TBMP. Highlighted in yellow are the 11 participants that were markedly less accurate than the rest of the sample.

As can be seen in Table 4.11, no differences were found between the TBPM deviant group and the TBPM not-deviant group in their scores of IQ, AQ, working memory or executive function. Additionally, the performance in the other timing tasks such as temporal generalisation and sensitivity thresholds do not explain the either the performance in the TBPM task.

Table 4. 11: Comparison in scales, cognitive tasks and timing tasks between individuals with deviant and not-deviant TBPM abilities

	FSIQ	AQ	CORSI	TOL	Threshold	TG accuracy
Deviant	119 (9.8)	31.06 (13.38)	5.53 (1.13)	27.6 (5.8)	117.12 (59.56)	0.78 (0.09)
Not-deviant	117.16 (11.61)	28.2 (13.87)	5.52 (0.9)	26.43 (7.01)	127.89 (95.46)	0.76 (0.08)
t	0.624	0.738	0.335	0.647	-0.536	0.992
p	0.538	0.467	0.974	0.523	0.595	0.331
Cohen's *d*	0.09	0.10	0.005	0.09	0.07	0.12

AQ: Autism Questionnaire; TOL: tower of London; TG: Temporal Generalisation.

4.6.3. Conclusion

Experiment 3 was dedicated to TBPM abilities in autism, finding comparable performance between groups. Additionally, deviant performance was observed in both groups. The exploration of the raincloud plots revealed a small trend of higher variability in the autistic group, and a higher frequency of less accurate responses. However, when a characterisation of the deviant performance was conducted the presence of autistic traits was not a factor to explain why that subset of participants responded as they did. These results suggest a conserved ability to produce durations in the range of few minutes in complex everyday activities.

All previous studies about TBPM abilities in autism have found differences between groups, but there are important methodological differences that may explain why the results in the current experiment show equality between groups. The first factor is the absence of a clock or time aid device. The availability of a clock gives the participant another element where to put their attentional resources making them take a decision of when to look, and accordingly, recalibrate their internal temporal production. It is possible that all that process increases the load of executive function demands of the task (e.g. multitasking), although this will need to run the task twice with a condition with/without time aids). The second modification is related to how scores were calculated and used. Altgassen et al. (2012) used a measure of *success* to calculate a score based on whether the participants executed the pre-planned behaviour in ± 60 seconds from the target, scoring 1-point if they actually did it. So, all the variance of the time measurement was eliminated and participants finally had only 3 possible scores 0, 1 and 2. The current experiment used the raw durations produced by the participants and a calculation of an index of accuracy. These measures allowed observing the performance in the task and its variability in both group and individual levels. Nevertheless, the analysis of the achievement rate that resembles the scoring system from Altgassen et al. (2012) showed no differences.

4.7. Relationship between different levels of time perception behaviour

If time perception systems differ between autistic and neurotypical individuals, it could be expected that this would be reflected in how the different tasks relate to each other. So, a correlational analysis was conducted between indices of the three experiments. Temporal sensitivity (Experiment 1) was correlated with the temporal generalisation accuracy ($r = -0.494$, $p < 0.001$), indicating that individuals with lower temporal thresholds had a trend to have better accuracy in the temporal generalisation task. Interestingly, a similar correlation was found between temporal threshold and pitch generalisation accuracy ($r = -0.486$, $p < 0.001$). No correlation was found between temporal threshold and TBPM ($r = -0.060$, $p = 0.631$), or in the analysis between TBPM with temporal generalisation ($r = -0.115$, $p = 0.359$) and pitch generalisation ($r = -0.029$, $p = 0.816$).

The previous analysis done separately for each group shows similar results. TBPM do not relate with thresholds (ASC: r = -0.071 p = 0.696; NT: r = -0.129, 0.472). In the same line, TBPM do not relate to temporal generalisation (ASC: r = -0.207, p = 0.247; NT: r = 0.196, p = 0.273), or pitch generalisation (ASC: r = -0.089, p = 0.619; NT: r = 0.028, p = 0.876). As shown in figure 4.13, thresholds are correlated to the temporal generalisation task in both groups (ASC: r = -0.516, p < 0.01; NT: r = -0.461, p < 0.01). The only correlation where the analysis by group do not mirror the analysis in the full sample is the correlation between thresholds and the pitch generalisation task, were the correlation was found in the autistic group exclusively (r = -0.637, p < 0.001), while the neurotypical group, although it follows the same trend, did not reach statistical significance (r = -0.282, p = 0.112). The difference between the correlation of the two groups was not significant (Z = -1.79).

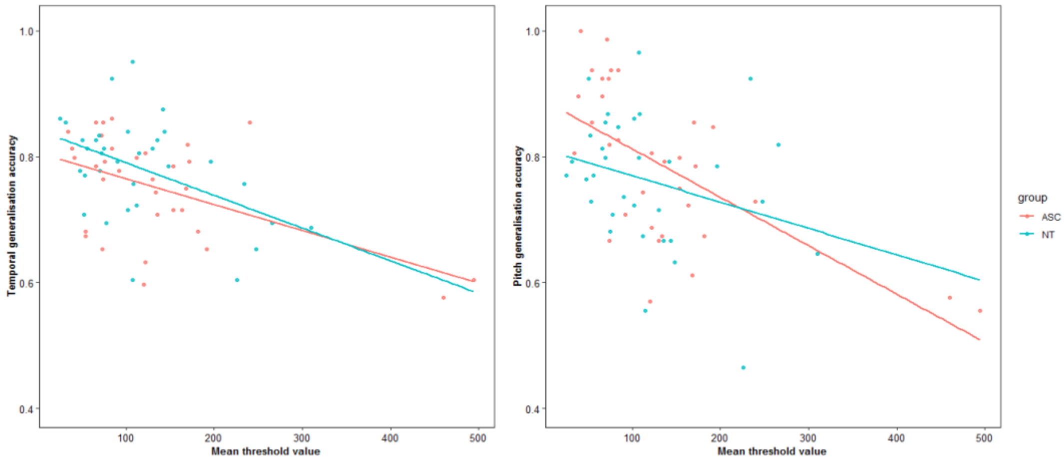

Figure 4. 13: Correlation between temporal sensitivity thresholds and generalisation tasks. In the left panel it can be seeing the similarity between the correlation slopes between the two groups in the correlation between thresholds and temporal generalisation. The right panel shows the correlation between temporal thresholds and pitch generalisation task, which was significant only for the autistic group.

4.8. Discussion

This study investigated whether time perception abilities are atypical in autistic individuals in comparison with neurotypical population across different levels of time perception behaviour. To this end 3 experiments were conducted. Overall the experiments showed a few individuals with atypical performance, although these were not characterised by belonging to one group or another. The first experiment showed no differences between groups in auditory sensitivity temporal thresholds. The second experiment revealed comparable performance in interval timing through a temporal generalisation task. The third experiment worked with a TBPM task and no significant difference in time perception abilities between groups in more complex contexts and longer durations (minutes instead of milliseconds). Furthermore, relationships between the tasks of the different experiments show the same pattern in both groups, with thresholds being correlated with the accuracy in the generalisation tasks, which suggests a similar cognitive style in all participants disregarding whether they are autistic or not.

First of all, it is important to clarify that the condition of belonging to the autistic or neurotypical group was correctly attributed, and that the groups differed in relevant attributes. This is clear not only because of the proof letter with the diagnosis that was asked to the autistic participants to take part in the study, but also because the data showed patterns that are consistent with previous research. Indeed although both groups had a comparable IQ, the autistic group showed higher scores in the Autism Quotient, and they scored significantly higher on the GSQ, which is something that has been shown and discussed in several studies (e.g. Iarocci and McDonald, 2006; Leekam, et al., 2007; Simmons et al., 2009; Haigh, 2017). Furthermore, as was expected based in the work of Gowen and Hamilton (2013), the autistic group also scored significantly higher than their peers on the DCD questionnaire concerning apraxia. It can therefore be asserted that the groups were indeed different. Nevertheless, they also showed some similarities in their cognitive abilities since no significant differences were found in the working memory assessment or in the executive function tasks. Although, these comparable abilities were not expected since it has been shown that autistic individuals often present working memory (Suneeta et al., 2014; Wang et al. 2018) and executive function difficulties (Garcia-Villamisar and Dattilo, 2011), comparable performance has also been reported in both WM (Semino, Zanobini, and Usai 2019), and EF (Wang et al. 2018). These similarities and differences are relevant information to understand the results in the three experiments as discussed below.

Temporal sensitivity thresholds showed no differences between groups, suggesting that autistic individuals have intact abilities in their capacity to discriminate between two durations in the millisecond range, which is something that was expected since it has been reported before in auditory modality by Mostofsky et al. (2000), and Jones et al. (2009). This was also supported by the absence of correlation between thresholds and autistic traits. However, studies showing higher thresholds in autistic adults have also been reported using similar methods, although a smaller sample (N = 21) (Kargas et al., 2015). In fact, the general performance in Experiment 1 showed non-significantly higher thresholds in the autistic group, mainly caused by the presence of a few participants with very high thresholds (outliers). Nevertheless, the majority of the autistic group performed in a very similar way to the majority of the neurotypicals did. It is worth noting that the NT group also included a few participants with unusually high thresholds, although not as extreme as the autistic group. If temporal thresholds are mainly governed by sensorial processes (in this case audition), these results show that the auditory system of autistic and non-autistic individuals do not differ in their ability to discriminate between durations.

The second experiment made use of a temporal generalisation task to explore possible differences in interval timing. Additionally, a pitch generalisation task was also used, so if between-group differences were found, it would be possible to know whether these differences were due general perceptual/cognitive functioning differences, or if the differences were specific to the perception of duration. The first level of analysis was to test how accurate the participants were in the task, showing comparable performance in the 400 ms Standard version of the task, but reduced accuracy in the autistic group for 800 ms Standard version. However, the level of accuracy in the autistic group was exactly the same in the two versions, which can be inferred were equally difficult because they superimposed. So, it cannot be argued that the difference in the 800 ms version is evidence enough to conclude there was an impairment in the autistic group. In fact, the comparison between groups in the full task (average between the 400 and 800 ms versions) shows no differences either. Exploration of the distribution of the accuracy shows that participants with low accuracy were present in both groups in the 400 ms version (even with more frequency in the NT group), but in the 800 ms version only the autistic group had a few individuals with low accuracy. These differences are at an individual level of analysis, and seem to be driving this effect. Thus they do not constitute strong evidence to support the idea of impairment in autism.

In the general performance on the temporal generalisation task, no differences were found between groups. All the analyses conducted consistently showed that the inclusion of the condition of belonging to one group or another (being autistic or not) was not a factor explaining performance in the task. Moreover, both groups showed good adjustment to scalar properties. These results support the findings of Jones et al. (2017) who found comparable performance in a temporal bisection task in the visual modality. Additionally, although Falter et al. (2012), found reduced sensitivity in the autistic group in a temporal generalisation task (also working with adults), they showed a higher consistency in the responses of the autistic group across different durations. One of the reasons that may explain this similarity between groups in Experiment 2 is that the groups had no differences in working memory, which is a strong component in the task. Unfortunately, Falter's study did not measure working memory, so it is not possible to know whether that is the reason why they reached a different result (in terms of time sensitivity). This is an important point since although different studies match participants by IQ, that does not mean they are equal in their working memory abilities and in fact, these two assessments are not necessarily correlated (as shown in this study). So, it would be a good practice for future research in interval timing in autism (or other conditions) to assess working memory in order to allow more accurate explanation of results and comparison between studies. More research is needed to find which type of working memory better accounts for the working memory abilities employed in a temporal generalisation task.

The temporal generalisation task was complemented with pitch generalisation task as a control task, and no group differences were found in this task either. This result is consistent with the findings of Issakson et al. (2018), which is the only study that employed a similar methodology in autism. In Issakson's study, they worked with an episodic temporal/pitch generalisation task where pairs of tones were presented in each trial, so the reference memory component is excluded from the SET model

(Wearden and Bray, 2001). Issakson's study showed less sensitivity to time in autism and comparable performance in pitch (although a trend for reduced sensitivity).

The last analysis conducted with the temporal generalisation data showed no correlation between the performance in the task and IQ. This result is supported by previous research in prospective time in autism (Wallace and Happé, 2008), although there is also evidence of poorer performance in the temporal generalisation low-IQ individuals in general population (Wearden, Wearden and Rabbitt, 1997), where low-IQ individuals had more difficulties remembering the standard duration.

An important point in Experiment 2 was that the results showing group equality are stronger for duration than for pitch. Actually in the pitch generalisation task, there seems to be trend to difference (although a weak one), in the direction of better performance in autism. This result is important in the context of this work, because it proves that the task was sensitive to small differences, and that the strong results in the temporal generalisation task are not task-specific. So, the conclusion of unimpaired prospective time abilities in autism is actually referring to the perception of durations and to related processes such as a memory component.

In Experiment 3 the participants were assessed in their TBPM and EBPM abilities using a modified version of the Dresden Breakfast Task. In comparison with the other experiments, the DBT-M involves more cognitive resources of executive function and working memory, because participants need to plan the task, follow that plan, switch between different activities, and follow rules of TBPM and EBPM. Given that previous research in higher-level time perception tasks in autism has consistently shown impairment in ASC (Casassus et al., 2019), the main hypothesis in this experiment was that the autistic group would be less accurate in the production of the two tested durations (1 and 3 minutes). However, the results showed the same level of achievement rate, and no differences between groups in the accuracy of the produced duration. There was comparable performance in the butter subtask; although outliers were present almost exclusively in the autistic group. Also, no trends were observed in terms of under or over-production in either group. In the Tea subtask, on the other hand, the participants of both groups were notably more accurate in comparison to the butter subtask, and the autistic group showed flatter distributions than the neurotypical group. These results together suggest that autistic and neurotypical individuals are comparable in their TBPM abilities, although the group of autistic individuals showed more variability between individuals in their temporal productions. Future research using this task could include more subtasks per duration to be produced, in order to check for individual variability.

As stated above, the TBPM results are in conflict with previous results using similar tasks. This surprising result can be explained by two methodological differences in this experiment in comparison with its predecessors. Firstly, the current experiment eliminated the availability of time-aids (e.g. clocks, watches, mobile phones) during the task. In addition, the scoring system in the current study was different, using the actual durations produced by the participants instead of the achievement criteria (also reported in this work). Previous studies using the Breakfast Dresden Task have included the presence of time aids and measure how many times the participants check on them. Additionally, they applied a scoring system based on ranges. For example, in Altgassen et al. (2012) if the participants completed the task within 60 seconds of deviation from the target, they were allocated 1 point, and 0 points if they did not. This has the problem that it takes out all the variation of times employed by the participants turning a continuous variable into a dichotomy (and even applying parametric testing on their analysis). This scoring system may be appropriate when the focus of study is memory in dichotomic terms (remembered/not-remembered); however from the time perception point of view, it loses its value. Hence, the current study chose to record and analyse the time employed by the participants to accomplish the task. Although including the clock can be very informative in terms of time management, it introduces noise to the measurement of time production. Additionally, since the participant is paying attention to the time-aid device waiting and expecting a specific number to appear or a position in the handles of an analogue clock, it could be argued that this is turning a time-based clue into an event (waiting something to happen). Furthermore, the presence of a clock gives a regular pace of rhythmicity (seconds) affecting the natural variance of the internal clock, or "recalibrating" the internal clock at each glance to the device. This recalibration effect has also been hypothesised by Labelle et al. (2009) who compared and interval production and TBPM task in durations of 30, 60 and 90 seconds (finding better accuracy in temporal production than TBPM). This may also add difficulty in terms of the executive function demands during the task. Having no clocks available forces individuals to self-monitoring their internal clock exclusively. But having the option of a time-aid adds an external cue that to some extent competes with their internal monitoring, which could be a source of anxiety, distress or even frustration during the task.

There are also possible caveats of the methodological changes of the Dresden Breakfast task that need to be acknowledge.d First, it wasn't possible to control for chronometric counting. However, this is true for both groups and because they were also focused on setting the table in the right way and compering what they were doing with the picture; reading and following their plan and re-reading the rules; and distributing attention to the EBPM tasks, it was not easy to count (and probably impractical). The other problem is the lack of precedent. As no studies have applied the task in the way this study did, there is no data to compare the performance of the participants.

Another result that was unexpected in the analysis of the Dresden Breakfast task was the lack of correlation between executive function and TBPM. A possible explanation of this is that the range of executive function abilities involved in performing the Dresden Breakfast Task are more and more complex than those measured by the Tower of London which mainly assesses planning. Additionally, no correlation was found between the Dresden tasks and working memory. Again, it is possible that the abilities measured using CORSI, which are mainly about spatial working memory, are not the same as those in place when performing the task. Future studies should attempt better characterisation of these processes to clarify the role they play in tasks such as those in the Dresden task.

The analysis of the retrospective timing task showed no differences between groups in the accuracy of their judgements, and the presence of outliers was found only in the neurotypical group. This result supports the finding of Issakson et al. (2018), who measured retrospective timing in 1-minute target estimation during 'dull' and 'fun' breaks in between other tasks. Interestingly, the absolute accuracy of the retrospective judgement was correlated with the IQ scores, showing that individuals with higher IQ are more accurate when judging durations retrospectively. This is interesting because IQ did not show an effect in the temporal generalisation task or the temporal sensitivity thresholds, so it is a result that opens a question of why IQ exerts an effect over retrospective judgements exclusively.

Given that the performance in the Dresden task was not explained by the group condition and deviant performance was present in both groups, a characterisation of this deviant performance was attempted in order to explain factors to may contribute to the atypical TBPM. The only finding from the analysis of the group of deviant performance was the confirmation that atypical performance is present in both groups, but none of the variables assessed in this study explained why they performed as they did. Future research should attempt a follow-up process in those outliers to confirm that they actually perceive time differently, but also to try to understand the reasons and possible impact in real-life. Additionally, the task showed no relationships with the other timing tasks, so there is no evidence so far that high-level temporal processing is underpinned by the same processes underpinning the perception of duration in interval timing.

The literature about time perception in autism (and in other conditions) often cluster different studies together as one piece of evidence, disregarding that those studies could be referring to very different processes. However, this study is the first to show that there is a correlation between time sensitivity and interval timing. If someone has lower sensitivity thresholds (than another individual), it means they can distinguish two stimuli as different when others cannot. On the other hand, someone being more accurate in the temporal generalisation task means that they remember the standard duration better that others. So, this relationship suggests that when people are more sensitive to the duration characteristics of the stimulus, they also remember durations better than others. Importantly for the aims of this study, this relationship was almost with the same strength in autistic and non-autistic participants, and then, it is evidence of the same cognitive processes operating in both groups for the perception of durations.

The current study is very consistent in showing no differences between groups in time sensitivity, interval timing and TBPM. There are however some limitations that need to be considered. First, the cognitive assessments of working memory and executive function are do not cover the whole processes they are measuring. It can be argued that visuo-spatial working memory does not reflect possible problems in temporal working memory. However, that would have appeared in the temporal generalization task. In the case of TOL, this is a task that does not assess the full complexity that executive function entail and is restricted planning abilities. Future studies could attempt a full executive function assessment to measure its possible influence in the different timing tasks. However, planning is highly relevant for the breakfast task. Another limitation is that this study covered only the auditory sensory modality. Additionally, sensory integration has been shown to be impaired in autism, which is something this research did not tackle. However, if the ability of autistic individuals in integrating time information with other cognitive processes is the main problem, this study would have shown differences in the Dresden Breakfast task. Additionally, this study and its three experiments had very clear instructions of what to do and so it is not surprising that participants made the effort to respond as accurately as possible even if that is not the way they behave in everyday life. In fact preliminary results of this research were discussed with a group of autistic adults (Expert by Experience group organised by BEAM Lab at University of Manchester), and they referred that if they are asked to follow certain instructions they will probably perform as they were asked (a common issue in well controlled lab-based experiments). But, if that was indeed the case, some differences are likely to have appeared in the Dresden Breakfast task, because they were instructed to do many other things not-time related at the same time (although this was not controlled). Finally, there is some evidence that the problem in time perception in autism is to be found in the timing of long durations of several seconds and minutes and not in the milliseconds range (Allman, 2012). In fact our results showed a trend to significant correlations between the accuracy in the temporal generalisation task and some of the questionnaires (including the AQ) only in the 800 ms standard version of the task. Future research could address this problem adding a third (and fourth eventually) longer standard durations in the temporal generalisation task (e.g. 1200 ms) to determine if the trend to significant correlations becomes stronger along with the standard duration. This is a question that future research will need to answer, but it involves some methodological problems, since the load of memory processes increases with longer durations in ways that is difficult to specify. But once again, if that would be the case, differences would have been appeared in the breakfast task, and, possibly in the retrospective judgements.

In conclusion, all these results together provide evidence for typical time perception abilities in autism across different tasks and levels of complexity, so it cannot be claimed that ASC is characterised by a time perception impairment. Although there are some autistic individuals that seem to have a different perception of durations, they are a small fraction of the group and atypical performance can also be observed in non-autistic individuals. There is still a remaining question about what type of behaviours and timing processes are those where autistic individuals experience problems. There is no doubt that more research is needed specially in higher-level time processing. From that cluster of abilities, this study only covered TBPM, which is, amongst the higher-level time processing cluster, the one with more links to interval timing.

5. Chapter 5: General Discussion

5.1 Review of findings

As was explained in the preface, this thesis was initially motivated by the question of whether autistic individuals have an impairment in time perception, and how such impairment impacted in other cognitive and social atypicalities that are common in the condition. The first step was to conduct a systematic to review to understand what is currently known about whether abilities related to the perception of duration are impaired and/or conserved. Autistic-like traits were then assessed in the general population to determine if they were affecting the internal clock or driving the perception of duration in any particular direction; for example to underestimate durations. Third, a cross-sectional study comparing adults with and without ASC was conducted using different empirical tasks from psychophysics experiments to more complex real life situation. This general discussion summarises and integrates the results from these three approaches, but also on the main problems encountered throughout all the stages.

5.1.1 Time perception spectrum disorder: different tasks, different cognitive processes, and the need for a clear taxonomy to understand the literature.

At the initial stage of reviewing the literature different problems emerged. In the first place, it was clear from the beginning that most of the literature consisted of underpowered studies, mainly because of small sample sizes. But even more importantly was the problem that evidence from different cognitive processes related to the perception of duration, were being used as if they were all measuring a unique cognition called 'time perception'. So, regardless of whether a study was focussed on sensorial issues or studying the understanding of past and future, they were used as a evidence for a generalised time perception impairment in autism. This is important because there is evidence of an absence of a strong relationship between the different time perception levels (Williams et al., 2019). In fact, this study (Chapter 4) is one of the few showing a correlation between temporal sensitivity and interval timing. This distinction about how different tasks may involve different cognitive processes has been shown even in tasks that are very similar (from the same cluster of time perception behaviours) as *simultaneity judgements (SJ)* and *temporal order judgements (TOJ)* (Recio et al., 2019). This lack of association has also been reported between interval production and TBPM (Labelle, et al., 2009). Hence, it seems pertinent not to mix the evidence from different cognitive processes to argue a conclusion as if they were all the same. Based on the complexity of the cognitive behaviour to be assessed, the literature was classified into three main clusters (i.e. temporal sensitivity, Interval Timing and Higher-level time processing).

Previous reviews have attempted a different approach in clustering the studies on time perception in autism; classifying the studies according to whether they are working in the millisecond or multi-second ranges (e.g. Allman and Falter, 2015). However, in the millisecond range there are experiments using several time sensitivity tasks and interval timing tasks, even though the cognitive model on which those tasks are based are very different. Additionally, the evidence about having different time perception mechanisms for short and long durations is also scarce (and usually distinguishing as short interval those shorter than 100 ms. See Box 1 in Ivry and Shlerf, 2008 for an example of this line of research), so it seemed more appropriate to cluster the studies according to the tasks they used.

This taxonomy allowed the reading the evidence from a different perspective and revealed different consistency of findings across studies depending on the level. While evidence was very mixed in the sensorial domain, it became more consistent with the complexity of the cluster, reaching full consistency in the high-level temporal processing level. This suggests that the involvement of other cognitive processes play a role in temporal judgements, and other ongoing processes not related to the perception of duration (e.g. multitasking), are factors that must be considered in time perception research. This is particularly relevant when a study aims to characterise cognitive processes in conditions as diverse as autism, which has been shown to be atypical in different cognitive processes, that can be expressed in different forms within the spectrum. So, this taxonomy should be useful not only for time perception research in autism, but also for researching other clinical populations that have been reported as impaired in their time perception abilities (e.g. Parkinson Disease).

The design of the study presented in Chapter 4 was a consequence of the findings of the systematic review. For example, the inclusion of a TBPM task was chosen because it was hypothesised that increasing other non-temporal cognitive demands would decrease the performance in autistic participants. Although the Dresden Breakfast task showed no significant differences between groups, the findings regarding conserved abilities in TBPM in the absence of clocks in autism is an important result. This result would not have been reached at all without the review done in Chapter 2. Additionally, the inclusion of working memory and executive function measurements was also a consequence of the same theoretical work. The fact that no differences were found between groups in these other cognitive processes, allows for hypothesising of why no differences between groups in the timing tasks were found. For example, a possible explanation is that the comparable performance in TBPM could be partially rooted in the autistic and controls comparable cognitive abilities of working memory and executive function processes.

The variability of the autistic spectrum is another source of misleading conclusions in the literature that surprisingly has not been paid enough attention in time perception research. This has been now exposed by the new formats of plotting the data (e.g. violin and raincloud plots), that show information that was previously hidden in bar charts. A good example of this is the bi-modal distributions as shown in Isaksson et al. (2018; Figure. 2), where half of the autistic sample had comparable performance with the group of neurotypicals, and the other half were atypical in their assessment of temporal thresholds. In fact Isaksson's study acknowledges that the means do not accurately represent the performance of the group. This type of observations should encourage researchers to perform analyses that take into account individual differences and possible subgroups when studying autistic samples.

5.1.2 The strength of the presence of autistic traits does not affect the perception of durations.

Chapter 3 was dedicated to two experiments investigating whether autistic-like behaviours affect the perception of durations. The main assumptions for these experiments were that (1) autistic traits are normally distributed in general population; (2) the strength of the presence of autistic traits affects other sensorial and perceptual processes (see Chapter 1), so this could be the case in the perception of durations as well; (3) human beings have an internal clock of some sort similar to what is proposed by the SET model; (4) under the presence of an effect of autistic traits on the internal clock, interval timing tasks would allow us to attribute those differences to the different components of SET model. The first assumption was found true. Indeed the autistic traits were normally distributed in the sample of the two experiments. The second assumption on the other hand exposed (again) that the perception of duration does not share the same characteristics as other perceptual processes. A critical point here is that under the absence of an external output of information, the temporal information seems to be a complex signal that is internally generated from the activity of different processes, where the sensorial activity appears to be only one of those factors. Hence, the effect that autistic traits have shown in other perceptual processes in general population (Roberts and Simmons, 2013; Horder et al., 2014) was not replicated in the case of the perception of durations.

Although the third assumption cannot be completely addressed by the experiments conducted in this thesis, the results obtained support the theory of the presence of a time perception mechanism similar to that proposed by SET. In the verbal estimation task the slope of the mean estimations was close to 1, and the data was very similar to previous published data in auditory modality using the same range of durations (as in Wearden et al., 1998). Additionally, Superimposition was tested in Experiment 2 showing relatively good fit. These findings together are good evidence of the scalar properties of timing, supporting an internal clock (at least) similar to that proposed by SET. Importantly, the latter is true regardless of the strength of the presence of autistic traits. Other time perception theories such as intrinsic models, based the perception of durations in estimations that are qualitatively defined, because each duration would correspond with a particular distribution of activity in the brain, often failing to adhere to the scalar properties. Therefore, although this study did not show evidence against other models of timing, the results presented in this thesis are difficult to interpret from those other models.

The finding of no differences in the verbal estimation of individuals with different levels of autistic traits supports previous findings in studies with autistic samples using this methodology (see Chapter 2). Although overall the studies using estimation methods to research time perception in autism show differences between groups, the only two studies working specifically with verbal estimation show comparable performance (Wallace and Happe, 2008; Sperduti, et al., 2014). An important point in the other studies using estimation methods is that all of them use a methodology that involves motor responses, which have been shown to be impaired in autism quite consistently (Gowen and Hamilton, 2013). Given that the results from one methodology – verbal estimation – consistently point in the opposite direction of the other methodology – time reproduction – and that the main difference between both tasks is the format in how the response is given, the most logical explanation is that the format of response is a factor in how individuals perform. However, Wallace and Happe (2008) also used a time reproduction task and found no differences, so the presence of differences in the other studies cannot be attributed to entirely to this motor factor.

The approach of working with general population to gain a better understanding of how autistic traits affect time perception processes has as one of its main strength that studies can be very well powered since it is possible to work with big samples, especially nowadays that online assessment are showing good quality of data (as shown in Chapter 3). But, as was discussed in Chapter 3, one of its caveats is that its results cannot be directly generalised to the autistic population, because amongst other reasons having high presence of autistic traits is not equivalent to have a diagnosis of autism. However, in the three experiments of Chapter 4 no correlation was found between the performance in the tasks and the scores of the AQ questionnaire in either the neurotypical or the autistic samples (or taken all together). The second experiment in Chapter 3 and Chapter 4 were basically the same (temporal generalisation) and the results are consistent in finding that the strength of the presence of autistic traits does not affect how individuals perceive durations.

Regarding retrospective judgements, an interesting characteristic of this task is that its takes out the element of intentional attention that is present in the prospective timing tasks. Given that in the prospective tasks the instruction is to pay attention to duration, the majority of the participants will follow that instruction, even if they would not do so in natural circumstances. This has been shown in the context of the Weak Central Coherence theory in autism, where even if an autistic individual has a predominant cognitive style (e.g. attention to details), they can perform in a different way if they are instructed to (Happe and Frith, 2006). If we apply that idea to a verbal estimation task, it is possible that differences in perception of durations in everyday life are masked during the task because participants are actually trying to perform as instructed. However, this effect is unlikely in retrospective time judgement, because it is a judgement made without a warning, so they had no option of putting any special attentional effort into the task.

An interesting and novel finding from the study of autistic traits in the general population was how well the tasks responded in their remote application. This is the first time that interval timing tasks are applied online. For the same reason is the first time these tasks have been applied to such big samples. The fact that the data mirrored the data from previous studies in the lab, with a high level of accuracy in both verbal estimation and temporal generalisation, should encourage other researchers to explore this option for their data collection.

5.1.3 From psychophysics to everyday life duration judgements: No evidence for a time perception impairment in autism.

Chapter 4 was dedicated to characterising time perception abilities by comparing a sample of autistic adults and matched controls by age, gender and IQ. Three different experiments were used to represent the three levels of the proposed taxonomy in the systematic review. No differences between groups were found for any level. Although deviant performance was found in a few individuals in all the tasks, these were not uniquely from the autistic sample, although they were present in a slightly bigger proportion. These results were not surprising in Experiment 1 and 2, but it was unexpected to find comparable performance in the third experiment about TBPM. Given that all the previous experiments assessing TBPM have found impairment in autism, it is important to reflect on the possible reasons of the comparable performance found in Experiment 3.

A critical difference in the methodologies used in previous studies of TBPM in autism was the availability of a clock during the experimental session. As was explained in Chapter 4, this was a factor that could explain the discrepancy with the results from previous studies. A TBPM meta-analysis (Landsiedel, Williams, and Abbot-Smith, 2017) critically analyses the evidence of impairment in autism. The analysis of the literature concluded that such impairment was not related to time estimation, but to the executive function demands of the tasks. Their conclusion from the analysis of the literature is consistent with the results of Experiment 3. Taking out the availability of clocks, reducing attentional shifting and executive function demands in the breakfast task, changed the task in such way that the key component of the task was the temporal production, and not executive function. An alternative explanation could be that since our sample had comparable working memory and executive function abilities to the neurotypical sample, they were able to accomplish the task in a similar way. It is important to notice that these two factors are not mutually exclusive, and both may have affected the results. Also, it is relevant to remember that the two group samples were in fact different in other aspects, as was shown by the self-reports of dyspraxia, sensory atypicalities, and autistic traits. Moreover, the characterisation of the autistic sample as such, was confirmed by the diagnosis letter and the ADOS. Hence, this lack of differences between samples actually shows that autistic individuals are not characterised by a generalised time perception impairment.

An important point aside from the lack of significant differences in Chapter 4, is the possible clinical significance of differences that do not reach statistical significance. Previous studies have suggested an association between having an impairment in the perception of durations in lengths lower than 2-3 seconds, and the *psychological present* hypothesised by William James (Allman and Falter, 2015). However, the evidence of such association is very scarce. Even in those studies showing differences in temporal thresholds, the meaning of those differences in the individual's experience in everyday life is uncertain. Experiment 1 in Chapter 4 shows a non-significant difference between groups of around 18 ms, but there is no clarity of whether that could be significant at a clinical level. Moreover, in the TBPM task the autistic group did the butter subtask (1-minute production) in 91 seconds, while the NT group did it in 80 s. Although no statistical differences were reached, if those 10 seconds of difference are associated with a difficulty coordinating actions with another person, could be highly significant in a clinical level. These considerations exceeded the scope of this study and are still highly speculative, but they should be researched further in future studies using approaches that combine quantitative and qualitative methodologies.

Although this thesis shows strong evidence in favour of comparable time perception abilities in three different levels of cognitive complexity, there are some limitations that are important to be aware of. Firstly, as was explained in Chapter 1 in the sub-section dedicated to the Weak Central Coherence, although an autistic individual could have a particular cognitive style, they may function using a different cognitive style if they are asked to. Under the assumption of that proposition as being true, it is possible that the autistic sample behaved in a different way during the experiment compared to how they judge durations in everyday life, because they were following an instruction. However, this does not explain the absence of correlation between autistic traits and interval timing tasks in chapters 3 and 4 (because the sample was the general population and not a clinical group. Also, if that were the case it would be an effect present in most experiments, and the literature would consistently show comparable performance in time perception across the three levels of the taxonomy.

Further work needs to be done in order to improve the taxonomy of time perception processes. This thesis presents a first level of classification, but there are clearly subclasses within each cluster. This is particularly evident in the case of the Higher-level Time processing level. For example TBPM and Diachronic Thinking are very different cognitive abilities. For this reason it should be encouraged that future studies measure different time perception tasks, to see how they relate to each other and to if they do to what extent. For example, in the interval timing level will be important that future research measures estimation and comparison methods in the same sample. These avenues of work are important for research in autism, other conditions and basic research in general population.

Regarding time perception in autism, it is important to expand this study to other sensory modalities such as visual or tactile. This would allow not only to determine possible specific atypicalities for a particular sensory modality, but also to know whether the typical effect of judging sounds longer than lights is in fact present in ASC. If not, this could open new questions regarding a possible tendency to a higher equality in the attentional resources between sensory systems in autism (see Wearden et al, 1998 for a full discussion). Additionally, it has been suggested that different systems would be involved for supra-second and infra-second durations (e.g. Allman and Falter, 2015). Although there is no strong evidence supporting this hypothesis, it is possible that the components of SET weight differently at different time scales, which is something this thesis did not cover. For the same reason, it would be interesting to include other 2 versions of the temporal generalization task in the range of seconds as those tested by Allman et al., (2011).

In regards to TBPM, there is a need to develop tasks where several trials for the same duration can be measured without risking the ecological value and executive function demands of the Dresden breakfast task. A problem of this task is that the 2 durations for the TBPM tasks are measured only once. This would allow the statistical power to be increased and the analysis of individual variability in the temporal judgements. Additionally, it would be interesting to conduct the TBPM task in the classic version (measuring clock checks) and in the version presented in this study. The comparison of the two versions would be valuable to explore possible differences between autistic and neurotypical samples in the recalibration process that happens after the clock checks. For example, it could be hypothesised (following the work of Noel et al. 2016 and the hypothesis of weaker priors in autism – see introduction), that recalibration has a lower effect in autism, and that the recalibration process in time perception processes from different levels are ruled by common principles.

Another comparison that seems pertinent in the case of the Dresden Breakfast Task is to have a classic temporal production task in the same range of durations. Since the modified version of the task presented in this thesis involves a temporal production in a complex and cognitively demanding scenario, having the temporal production alone, would allow to suggest how many resources during the Dresden task are dependent on the time perception mechanisms.

An important limitation of Chapter 4 is that it is underpowered in statistical terms. Although the sample is bigger than most of the studies of time perception in autism in any of the levels of analysis, it is still underpowered. This is a permanent challenge in research with clinical population, but the successful experience with the online testing reported in Chapter 3 is an important precedent in the direction of well-powered research.

Finally, it would be important for the time perception research field to create a full cognitive characterisation of atypical time perception processes. This characterisation could be attempted by doing a follow up study with all those participants (from both groups of Chapter 4 for example) who show atypical performance, and including qualitative reports to understand the impact that atypicalities in different time perception tasks have in real life. This characterisation seems a logical step to give place to the designs of interventions to improve the quality of life of those who are impaired in their time perception abilities.

5.2 Conclusion

The analysis of the literature, the online study in general population and the three experiments presented in Chapter 4, mark a significant increase in our knowledge about (and ways of thinking about) time perception processes in autism. The findings in this thesis suggest that the autism is not characterised by a generalised impairment in the perception of duration. Autistic adults presented with comparable performance in a sensorial level in auditory modality, which is the most basic level at which a duration is perceived. Autistic individuals also performed similarly to general population in their capacity to store a duration in memory and use it as reference to be compared to other durations. Additionally, this work added evidence about the good adherence of autistic individuals to the scalar properties of timing, and the findings are consistent that the presence of autistic traits does not speed-up or slow-down the internal clock. Finally, this research showed that autistic individuals (or at least a good proportion of them) can manage long durations in everyday life activities, at least in those sharing similar working memory and executive function abilities with neurotypicals.

The evidence presented in this thesis does not mean that autistic individuals have no difficulties managing time across different context in everyday life activities, something that actually they have expressed in anecdotal reports. However, the source of those issues does not seem to be rooted in the perception of durations. It is always important to bear in mind that the concept *time* is used colloquially in different ways to refer to different processes. The specification of which cognitive differences underlying the reported problems with time in phenomenological and personal accounts is still an open question that requires further exploration.

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Appendix A.1

Outliers' Online verbal estimation (Chapter 3)

This appendix shows the data from the outliers in the verbal estimation task.

Five outliers did not have an AQ-short score. Four of the outliers presented reached the >70 cut-point for Asperger Syndrome.

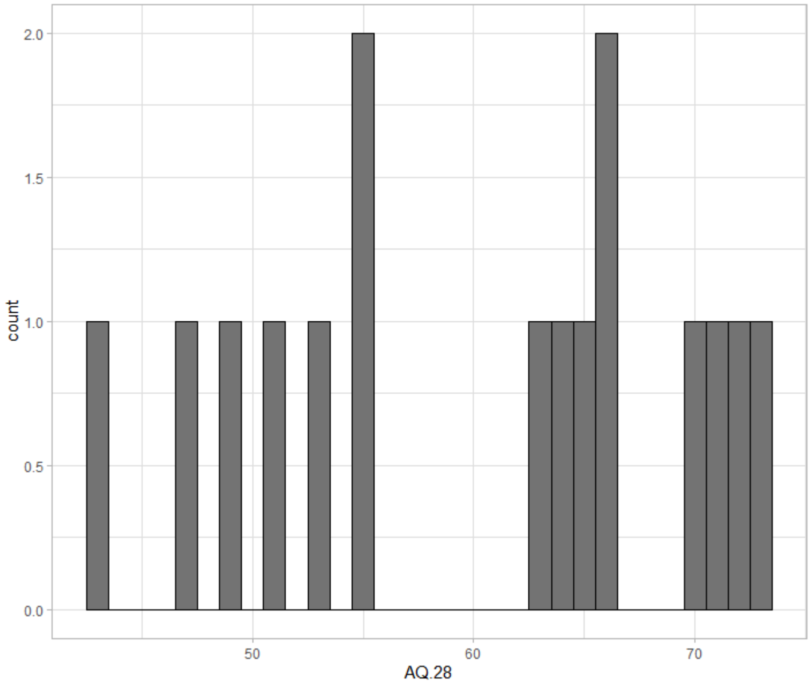

Figure A1.1: Histogram of the AQ-short scores in the outliers

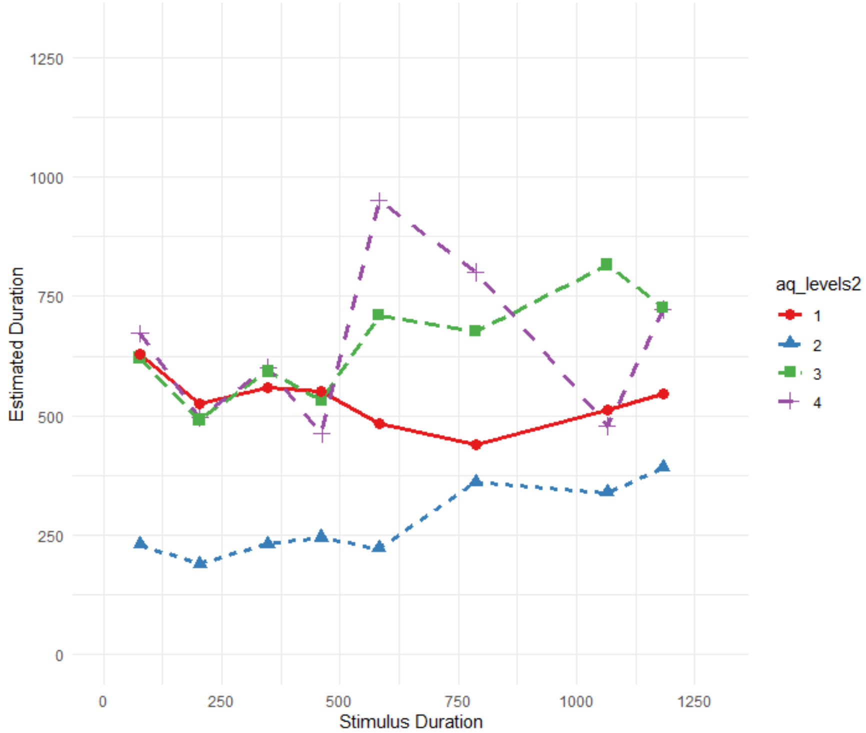

Figure A1.2: Estimated duration plotted against the stimulus duration by level of autistic traits. The data is clearly deviant regardless the strength of the presence of autistic traits.

Appendix A.2

Outliers' Online Temporal generalisation (Chapter 3)

From the outliers in the temporal generalisation task, 7 had high scores.

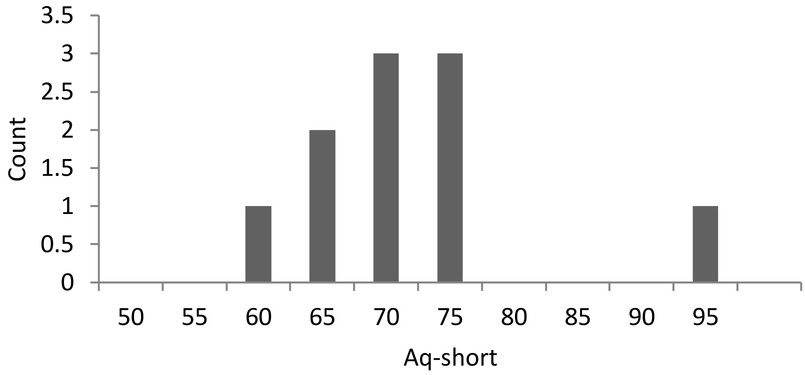

Figure A2.1: Histogram of the AQ-short scores in the outliers of temporal generalisation task.

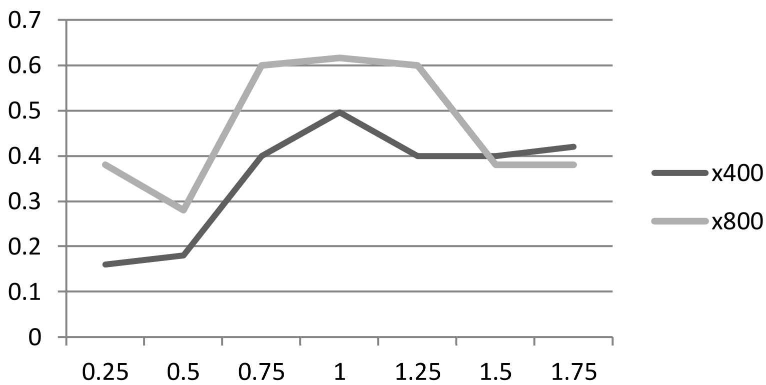

Figure A2.2: Temporal generalisation gradients for the 400 ms and 800 ms standard versions of the task.

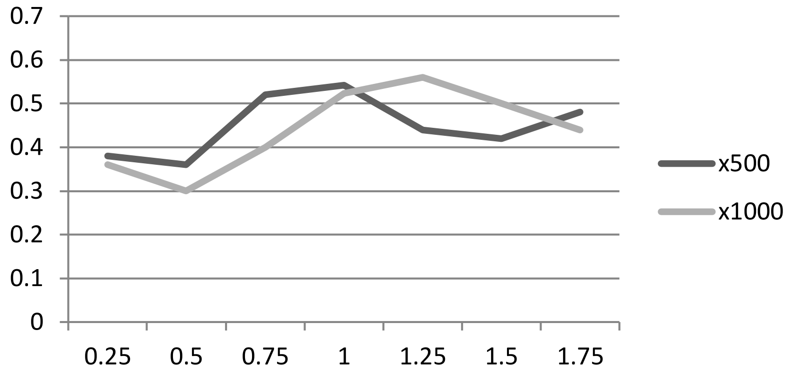

Figure A2.3: Pitch generalisation gradients for the 400 ms and 800 ms standard versions of the task.

Appendix B

Participant code:___________________________	Task 1	Task 2
Time Based-PM	Butter	Tea
Achievement		
Time of the beep marking the beginning of the task / finishing pouring the water into the teapot		
Time marking the end of the sub-task (reaching the fridge/ pouring the water into the mugs)		
Number of activities during elapsed time in the subtask		
Perception of difficulty		
Strategies to track time		
Event-Based-PM	Water	Toaster
Achievement		
Time from cue in seconds		
Number of unrelated activities before executing the action		
Number of activities to achieve the goal of the subtask		
Perception of difficulty		
Comments		