Auditory and linguistic processing in autism: evidence from production and perception

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

Autistic individuals may possess enhanced auditory abilities, but their language profiles are highly heterogeneous. Such inconsistent results, to a certain extent, can be explained by not controlling for confounding variables (e.g., cognitive abilities), and by not using closely matched stimuli across domains. The current thesis comprised three main aims: (1) to investigate whether autistic individuals will show superior performance at the tone and intonation perception in a foreign tone language compared to controls; (2) to explore the differences in groups' comprehension abilities whilst recalling sentences in different conditions (e.g., spoken vs sung sentences); and (3) to investigate autistic individuals' expectancy on both perceptual and production tasks using closely matched linguistic and melodic stimuli.

In Study 1, no group differences were found on any Mandarin tone or intonation discrimination task, and we did not identify a subgroup of autistic individuals with superior perceptual abilities. Study 2 preliminary findings showed no group differences when recalling sentences, whereas the results from an online study showed impaired sentence recall in the autism group compared to controls. In Study 3 autistic individuals produced more 'the most frequent' responses on the melody completion task in the high expectancy but not in the low expectancy condition, compared to controls. Both groups performed equally well on the sentence completion task across conditions, whereas overall, autistic participants produced more NA responses than controls. However, none of these differences reached significance after applying the Bonferroni correction. The groups did not differ in their ratings across the tasks (sentences/melodies) or the conditions (high/low expectancy) and did not differ in their RTs across the tasks/conditions.

The findings of this thesis provide evidence of either intact or enhanced auditory processing and either intact or impaired speech processing in autism. Future studies are warranted to further explore the underlying processes of production and perception processing in autism.

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1 General introduction

1.1 Music and language processing: differences and similarities

Music presents one of the oldest forms of art (Dobrota, 2012), whereas language presents a culturally specific communication tool (Hauser et al., 2012), and both are of immense importance to humans. There is a growing body of research investigating music and language processing in parallel, and reporting that one influences the other (Besson, et al., 2017; Jäncke, 2012; Kraus & Slater, 2015; Schön, et al., 2004; Tillmann, 2012). Yet, there are some differences between the two domains that need to be addressed first. For example, a concept of tonality exists as part of music theory, but no such concept exists in language. In addition, if we hear a melody that is missing a couple of notes (i.e., an interval), we may perceive it as wrong even if we have no musical training (Zatorre & Baum, 2012). Nevertheless, if we remove some words for conciseness, such a sentence will not necessarily be perceived as wrong unless it is ambiguous (Bailey & Ferreira, 2003) or contains background noise (Wendt et al., 2016). On the other hand, a concept that exists in both domains is the presence of pitch. In music, pitch carries the information about tonality (Krumhansl, 1990) and harmonic changes (Holleran et al., 1995), whereas in tonal languages (e.g., Mandarin) the same segments can convey different meanings with different lexical tones, depending on the pitch contours (Liu et al., 2012).

Both music and language can convey emotions (Patel, 2008), and both use pitch (position of a sound in music, and the meaning of words in language, Camacho & Harris, 2008). Pitch represents a basic musical facet (sound going up vs down), while in tone languages such as Mandarin, it has a linguistic function. In a review conducted by Besson et al. (2007) it was found that musical expertise improves pitch processing in both music and speech. This is in line with the OPERA hypothesis (Patel, 2011), which postulates that musical training indeed has a positive effect on speech encoding if the following five conditions are present: Overlap, Precision, Emotion, Repetition, and Attention. In addition, we need to use memory capacity to store information appropriately when perceiving and comprehending novel speech and/or music stimuli (Jackendoff, 2009). Finally, both speech and music processing involve 'creating expectations of what is to come' (Patel, 2008).

Another link between music and language comes from studies looking into the effects of musical training on linguistic abilities and verbal short-term memory. Researchers have found greater verbal short-term memory span in people with musical training when compared to people with no musical training (Franklin et al., 2005), and an improvement in their verbal short-term memory (Chan et al., 1998) due to musical experience. Finally, studies have also found a positive link between musical training and comprehension and vocabulary (Swaminathan & Gopinath, 2013). Apart from behavioural studies listed above, a variety of neuroimaging studies investigated brain regions' overlap in music and language processing. For instance, studies exploring linguistic syntactic violations (e.g., Osterhout, 1997) using event-related potentials (ERPs) have primarily focused on the presence of the P600 component but Patel et al. (1998) found that structural incongruities elicited P600 in both musical and linguistic domains. Such finding created a ground for studying music and language in parallel due to their shared cognitive mechanisms using other techniques such as functional magnetic resonance imaging (fMRI) where interaction between musical syntax (harmony) and linguistic syntax was found in Broca's area (Chiang et al., 2018; Kunert et al., 2015).

Conflicting studies have caused a debate about whether music and language processing share the same neural mechanisms or if they are independent of each other. For example, there are people with Congenital Amusia (inability to recognize musical tones or to reproduce them) (Peretz & Hyde, 2003) that do not have aphasia (language disorder caused by brain damage) (Damasio, 1992) and the other way around (e.g., Peretz et al., 1994; Piccirilli et al., 2000, Ayotte et al., 2002). Such selective cases support the idea that music and language processing operate independently of each other. In order to solve such contradictions, Patel (2003) proposed the shared syntactic integration resource hypothesis (SSIRH). According to this hypothesis, music and language involve both domain-specific (independent from each other) processes and shared processes. In other words, the musical syntax differs from linguistic syntax, but they both elicit shared syntactic representations (Patel, 2012). For instance, although aphasic people primarily have difficulties with language comprehension, this, in turn, affects their musical perception as well, which supports Patel's (2003) SSIRH.

In the following sections, how perceptual abilities may differ from production abilities will be discussed, as will how these vary between different modalities in autism (auditory vs linguistic). In addition, a discussion of how several factors may contribute to enhanced auditory abilities in autism (e.g., tone language background) is included, as well as how musical training and/or music therapy can help enhance linguistic abilities in autistic individuals.

1.2 Defining autism

The pioneer in the field of autism used the exact words 'autistic aloneness' to explain the behaviour of autistic children (Kanner, 1943), whereas Asperger (1944) used the term 'autistic psychopathy' while both authors mentioned 'exceptional musical memory'. Since the 1940s, many changes in autism diagnostic criteria have been applied, which has also led researchers to explore comorbidities with autism. For instance, there is ongoing debate on whether developmental language disorder (DLD) and autism are distinct conditions or if they can co-occur within each other. Georgiou and Spanoudis (2021) found that a subgroup of autistic children exhibit language difficulties comparable to those with DLD, which supports the idea that there is a subgroup of individuals with language impairment among the autistic population. Similarly to autism, DLD is also a heterogeneous disorder, meaning that individuals can show quite different symptomatology (e.g., expressive language intact but receptive language impaired) (Bishop, 2014). Yet, individuals with DLD have specific clinical markers such as errors of tense marking (e.g., Calder et al., 2021); whereas this is less clear in autistic individuals who may exhibit subtle or no language difficulties (Whitehouse et al., 2008). Turning to other comorbidities, studies suggest that 91% autistic children and adolescents meet criteria for at least one co-occurring diagnosis, such as attention deficit hyperactivity disorder (ADHD), and anxiety disorders (Mosner et al., 2019), although this is more common in autistic women (Rynkiewicz et al., 2019).

Above mentioned findings highlight the highly diverse nature of autism, and the variations in how it manifests across autistic individuals, which is beyond the scope of this thesis (Rynkiewicz et al., 2019).The current autism DSM-5 criteria cover the following core deficits: impaired communication, repetitive behaviour, and impairments in social communication, where the severity is based on these three core symptoms (American Psychiatric Association, 2013). In addition, clinicians must specify if one of these is present: With or without accompanying intellectual impairment, With or without accompanying language impairment or Associated with a known medical or genetic condition or environmental factor (APA, 2013). Throughout this thesis, autistic-preferred terminology will be used to avoid ableist language (Bottema-Beutel et al., 2021), and to acknowledge individual differences in autistic individuals' cognitive profiles.

1.3 Music and language processing in autistic individuals

Researching autistic individuals' processing abilities across melodic and linguistic domains is of special interest since, conversely, such individuals tend to show certain advantage on music-based tasks (e.g., Chamak et al., 2008) but often have impaired linguistic profiles (Tager-Flusberg, 2000). For example, early studies investigating musical abilities in autistic individuals have used the term 'savant' trying to explain individuals who show exceptional musical abilities (e.g., Howlin et al., 2009; Happé, 2018). Indeed, around 17% of autistic people exhibit some type of exceptional musical ability (Meilleur et al., 2015). Such unique skills can be applied to other areas as well, rather than just the musical domain, including memory, visuospatial abilities, calculation, and drawing (Meilleur et al., 2015), and are not only genetically dependent but also environmentally dependent.

Apart from empirical evidence suggesting that some autistic individuals may exhibit superior auditory abilities (e.g., Jones et al., 2009), it seems that language background also plays a role in both auditory and linguistic processing. Tone language speakers create strong associations between pitches and word meanings during both speech production and speech perception (Deutsch et al., 2004). Research has shown that native tone language experience is related to altered responses to linguistic and non-linguistic stimuli (Deutsch, et al., 2006). In turn, tone language speakers (e.g., Mandarin) are better at pitch discrimination tasks than English (non-tonal) speakers (Pfordresher & Brown, 2009; Hove et al., 2010).

Turning to autistic individuals who speak a tone language, they also have a certain advantage on linguistic tasks due to their tone language background. For instance, they have difficulties with producing aspect markers (attached to verbs to indicate aspect; Zhou et al., 2015) but show unimpaired comprehension (Su & Naigles, 2021), compared to autistic non-tonal speakers who often show impaired comprehension (Rapin & Dunn, 2003) despite having intact decoding skills (Huemer & Mann, 2010). However, both tone and non-tonal speaking autistic individuals have difficulties with processing lexical information (Wu et al., 2020) but often show intact or enhanced processing of non-linguistic information (Heaton, 2005; O'Riordan & Passetti, 2006).

The following three subsections will explore the empirical evidence investigating auditory (i.e., non-linguistic) and linguistic processing in autistic individuals across perception and production whilst considering factors that may influence linguistic and auditory processing (e.g., language background: presence vs absence of lexical information).

1.3.1 Perceptual abilities in autistic individuals

Previous research has found superior performance among autistic individuals on various perceptual tasks, such as identification of local pitch changes (Foxton et al., 2003; Mottron et al., 2000) and memorizing pitch information (Heaton et al., 1998; Heaton, 2003). A study which used both musical and linguistic stimuli found enhanced perceptual abilities in autistic participants whereas controls showed superior sentence comprehension (Järvinen-Pasley & Heaton, 2007). On the contrary, studies that investigated how tone language speaking autistic individuals perceive lexical (i.e., semantic) information reported that such individuals have impaired categorical perception of Mandarin tones (Chen et al., 2016). Thus, it is plausible that enhanced perceptual abilities in autism are only present when there is no lexical information to process (i.e., perceiving non-linguistic stimuli) irrelevant of the language background (tone vs non-tonal language). This is in line with studies finding enhanced discriminatory abilities in autism for non-speech stimuli but not for speech stimuli (Yu et al., 2015).

Often preserved musical abilities but persistent language impairments in autistic individuals (Lai et al., 2012) have led neuroimaging studies to investigate both domains in parallel. For instance, Sharda et al. (2015) used a passive-listening fMRI paradigm with spoken words, sung words and piano tones. It was found that autistic children's brain regions activated similarly to controls during the sung-word perception. Conversely, reduced brain activation was found in autistic children during the spoken-word perception compared to controls, suggesting that musical and linguistic processing may function more ‘independently’ in autistic individuals than in controls. That is to say, that although there is an overlap in the auditory cortex when processing musical and linguistic stimuli in autistic individuals, there is also a significant no-overlap that is not present among controls (Rogalsky et al., 2011). Other neuroimaging studies that compared spoken and sung stimuli in autistic individuals have reported the same pattern of results; finding opposite lateralisation for spoken words versus pitch in song (Sharda et al., 2015), which could be related to different integration of information in autistic individuals, when compared to controls. This is in line with behavioural studies reporting that autistic individuals have difficulties with using the context appropriately and tend to produce narratives diminished in semantic quality when compared to controls (Losh & Gordon, 2014).

Previous literature consistently claiming superior perceptual abilities in autistic individuals has led to the creation of perceptual theories in autism, such as the Enhanced Perceptual Functioning model (Mottron et al., 2006). According to this model, perception plays a different and overriding role in autistic cognition (Mottron et al., 2009). Conversely, some authors argued that the EPF is only confirmed in studies that relate to perceptual discrimination abilities (e.g., Plaisted, 2001) but superior abilities in autistic individuals have been found on various tasks including detection, matching, memorisation, and categorisation (Mottron et al., 2006). The Updated EPF model noted eight principles of the updated model's version, emphasising the fact that domain of special ability (which varies from each autistic individual), and some aspects of the autism phenotypic variability led to exceptional perceptual abilities in this group (Mottron et al., 2006). Nonetheless, it should be noted that some studies found superior perceptual abilities only in a subgroup of autistic individuals (Heaton et al., 2008b; Jones et al., 2009) rather than in the entire group.

Another theory that relates to both perceptual and production abilities in autism is The Weak Central Coherence (WCC) (Frith, 1989; Happé, 1999; Happé & Frith, 2006). According to this model, autistic individuals tend to exhibit a specific cognitive style where they focus on particular details, rather than on the integration of information in its global context. The model has been studied in different domains, including visuospatial (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001), auditory (e.g., Bonnel et al., 2003) and linguistic (e.g., Happé, 1997). The results of these studies supported the view of WCC by either confirming superior detail-focused processing (Bonnel et al., 2003) or reduced integration of context in autistic individuals (Frith & Snowling, 1983; Happé, 1997). For instance, on linguistic production tasks, autistic individuals tend to complete sentences in a 'local' way (Booth & Happé, 2010), showing impaired integration of lexical information, whereas this ability is enhanced in the auditory domain (Foxton et al., 2003).

Study 1 will investigate participants' perceptual abilities, as part of discrimination tasks of a foreign pitch including speech and non-speech stimuli. In addition to the main experimental tasks, "lower-level" perceptual abilities will be tested using pitch thresholds.

1.3.2 Linguistic integration of information in autistic individuals

Language deficits are one of the core symptoms of autism (APA, 2013). Around 25%–46% of autistic children are minimally verbal past the age of 5 years (Norrelgen et al., 2015; Rose et al., 2016), while some autistic individuals remain nonverbal (Koegel et al., 2020). Verbal autistic children show delays in early language and communication development compared to typically developing children (Mitchell et al., 2006). At 12 months, autistic children understand significantly fewer phrases and produce fewer gestures, whereas at 18 months, they show delays in both comprehending phrases, and production of single words (Mitchell et al., 2006) when compared to controls. Relating back to often enhanced auditory processing in autism (Mottron et al., 2006), superior pitch discrimination is related to both current autism symptomatology and early-language milestones (i.e., delayed first words) (Eigsti & Fein, 2013).

Autistic individuals who exhibit normal language development still show highly variable linguistic profiles (Tager-Flusberg, 2006). A possibly different integration of information in autistic individuals comes from studies investigating Broca's area and its role in sentence comprehension in controls, such as syntactic processing (Friederici et al., 2000; Ni et al., 2000; Röder et al., 2002) as well as semantic processing (Gabrieli et al., 1998) as part of word reading (Fiez & Petersen, 1998). Broca's area is reported to be reduced whereas Wernicke's area is found to have increased activation during sentence comprehension in autistic individuals (Just et al., 2004), confirming reduced left hemisphere frontal activation in these individuals. Another Positron Emission Tomography (PET) study found the opposite hemispheric dominance during verbal auditory stimulation in autistic individuals when compared to controls (Müller et al., 1999).

These results led to a suggestion that there is atypical language dominance in autistic individuals, which in turn was a ground for setting a hypothesis about general under-connectivity (GU), and other studies whose findings are not consistent with the GU hypothesis (NGU) (Müller et al., 2011). Such inconsistencies can be explained by differences in methodologies where some studies investigated participants' answers without low-pass filtering (removing the 'noise' in the data) (Lombardo et al., 2010) whereas others applied low-pass filtering (Turner et al., 2006). Even given different methodologies, sample sizes, and data analyses (causation vs correlation), both studies with and without low pass filtering found abnormal functional networks in the autistic population, which could be related to the development of white matter in this population (Müller et al., 2011). Furthermore, although atypical lateralization is known to be related to language impairments, it has been found that more atypical asymmetries are linked to more substantive language impairments (Lindell & Hudry, 2013).

Language delay is often one of the first concerns of parents of young autistic children (Wodka et al., 2013), and early language skills predict broader outcomes for autistic children (Flippin et al., 2018). However, mechanisms underlying language deficits in autistic children remain underspecified. A prominent component of language behaviour is the use of predictions or expectations during learning and processing. The basic premise of prediction accounts is that information is processed by making predictions and testing for violations of expectations (prediction errors) (Weismer & Saffran, 2022).

Apart from behavioural studies, atypical integration of linguistic information in autism has also been studied using Event-Related Potential (ERP) (Márquez-García et al., 2022; Riva et al., 2022). ERP studies have shown that if a sentence stem invites a strong expectation for a missing word (e.g., It is hard to admit when one is..) where a word 'wrong' is highly expected (Arcuri et al., 2001), a larger N400 (negativity peaking at about 400 milliseconds after stimulus onset) ERP component would be present if we insert the word 'guilty' instead of 'wrong' (Kutas & Federmeier, 2011). However, studies investigating N400 in autistic participants either did not find any N400 effect (Dunn & Bates, 2005) or their N400 was delayed (Valdizan et al., 2003). This is in line with studies finding that autistic individuals tend to have difficulties with using the linguistic context appropriately (Jolliffe & Baron-Cohen, 1999), confirming that sentence context does not elicit N400 in autism group (Pijnacker et al., 2010).

Left inferior frontal (LIF) and right inferior frontal (RIF) brain regions are related to integration of information that contains semantic knowledge (Hagoort, 2005), world knowledge (Menenti et al., 2009), and speaker's information (Tesink et al., 2009). A study conducted by Groen et al. (2010) used an fMRI paradigm by manipulating the semantic- and world-knowledge sentences' expectations (semantic vs factual) and the content (congruent vs incongruent) in respect to speaker's characteristics (male/female, child/adult, and upper class/lower class) in autistic adolescents and their controls. The results showed that LIF regions did not differ between the groups in the semantic-knowledge and world-knowledge condition. However, autistic participants had significantly less active LIF in the social condition where they had to integrate speaker's information. This is in line with the theory of decreased functional connectivity in autism that predicts reduced activation during tasks where participants need to integrate information (Belmonte et al. 2004; Just et al., 2007).

In this thesis, linguistic integration of information will be tested as part of three studies. Namely, in Study 2 participants will be asked to repeat a sentence, under different conditions, such as changes in content (news-like, story-like, and nonsensical sentences), noise (presence/absence of noise), and form (spoken vs sung). Study 3 will prompt participants to continue or complete a sentence using only one word, depending on the context of high or low expectancy. Lastly, Study 3a will require participants to continue a sentence designed specifically to test the WCC account (Happé, 2005).

1.3.3 Auditory production abilities in autistic individuals

Due to reported enhanced perceptual abilities in autistic individuals in the auditory domain, it is worthwhile to explore the production abilities of music-based (i.e., non-linguistic) tasks in this population since production and perception abilities are reported to be closely related (e.g., Flege, 1993). For instance, Thaut (1988) compared improvised musical sequences produced by controls, autistic children, and children with intellectual disabilities. The children were asked to play the xylophone arranged in a pentatonic scale and allowed to continue playing until they came to a natural ending. Autistic children outperformed intellectually disabled children on rhythm, limitation, originality, and overall achievement score, whereas there were no differences on any measure between autistic children and controls. Interestingly, autistic children scored the highest on the restriction scale and the lowest on the complexity scale, when compared to the other two groups. This supports previous research suggesting that autistic individuals outperform controls on tasks that involve processing simple stimuli only (simple vs complex tones) (Bonnel et al., 2010; Samson et al., 2006).

Referring to auditory production tasks, quite a few studies focused on imitating prosodic pitch in autism (Chen et al., 2022; Wang et al., 2021; Wang et al., 2022). The results suggested that tone speaking autistic individuals show increased pitch variations when imitating lexical tones but performed similarly when imitating non-speech stimuli (Chen et al., 2022). Non-tonal speaking autistic individuals showed intact abilities whilst discriminating (both speech and music stimuli), identifying, and imitating statement-question intonation (Wang et al., 2022) spanning different age cohorts. In addition, controls outperformed autistic individuals on absolute pitch and duration matching for both speech and song imitation, but no group differences occurred on relative pitch and duration matching (Wang et al., 2021). Overall, these findings suggest that the autism group may particularly show intact or enhanced processing of non-speech stimuli but tend to exhibit either intact or diminished imitation accuracy, highlighting the complexity of variable cognitive and linguistic profiles in these individuals.

Other studies where autistic participants were asked to produce an answer in the auditory domain primarily focused on the effects of music therapy to either modify challenging behaviour (Møller et al., 2002) or produce speech. Indeed, verbal instructions coupled with melodic and rhythmic patterns with visual cues facilitate words' recall in autistic children (Thaut, 1988). Since many autistic children enjoy participating in musical interactive activities (Trevarthen, 1998), in turn, such activities can be beneficial for their communication development and use of expressive language (Wan et al., 2010).

The thesis will conduct two studies to test the auditory production abilities of autistic individuals and their typically developed counterparts. In Study 2, participants will complete a sentence repetition task that involves spoken and sung sentences, as well as different content types and the presence or absence of noise. In Study 3, participants will complete the Melody Cloze Task that will test their auditory production abilities while manipulating expectancy levels (low vs high expectancy). In Table 1.1, the main empirical evidence investigating perceptual and production abilities in either auditory or linguistic modality is presented.

Table 1.1

A summary of autistic individuals' performance across perceptual and production tasks in both auditory and linguistic modalities

Citation	Task	Intact performance in autism	Enhanced performance in autism	Impaired performance in autism
Foxton et al., 2003; Mottron et al., 2000	Identification of local pitch changes		X	
Heaton et al., 1998; Heaton, 2003	Memorizing pitch information		X	
Järvinen-Pasley & Heaton, 2007	Pitch discrimination		X	
Chen et al., 2016	Categorical perception of Mandarin tones			X
Lai et al., 2012	Speech vs song (passive paradigm)	X (Speech condition)	X (Song condition)	
Sharda et al. 2015	Sung-word perception	X		
Losh & Gordon, 2014	Producing narratives			X
Booth & Happé, 2010	Sentence Completion Task			X
Mottron et al., 2006	Auditory perceptual abilities		X	
Dunn & Bates, 2005; Pijnacker et al., 2010	Lingusitic context (N400)	X		

Jolliffe & Baron-Cohen, 1999; Brown et al., 2012; Groen et al., 2010	Linguistic/Social context			X
Bonnel et al., 2010; Samson et al., 2006	Pure tone discrimination		X	
Chen et al., 2022, Wang et al., 20222	Pitch imitation	X		

1.4 Individual factors that influence music and language processing

1.4.1 Absolute Pitch, Music Therapy, and Musical Training in autism

Only a small percentage of musicians possess Absolute Pitch (AP); an ability to identify/re-create a note without a guiding note (Hamilton et al., 2004), but there is a rather high prevalence of AP ability among autistic individuals (Brown et al., 2003). In addition, some studies reported a higher degree of autistic traits in individuals possessing absolute pitch APs than in non-AP individuals, and non-musicians (Dohn et al., 2012). Interestingly, there is also a higher number of autistic individuals who speak a tone language (e.g., Mandarin) and possess AP when compared to autistic individuals who speak a non-tonal language (e.g., English) (Deutsch et al., 2006), suggesting that tone language experience may be of particular advantage for autistic individuals when processing auditory information.

Music therapy plays a key role in the diagnosis and evaluation of children and adults with pervasive developmental disabilities (Reschke-Hernández, 2011). Music therapy assessment reveals strengths and weaknesses in core impairments (Wigram, 2000), including social interaction and communication. It is well reported that music therapy has positive benefits on language processing and social skills in autistic individuals where autistic children's communicative behaviours increase after individual therapy (Edgerton, 1994; Ghasemtabar et al., 2015; Lim & Draper, 2011; Walworth, 2007). In addition, intervention studies employing musical training showed an increase in speech processing in autistic individuals (Chenausky et al., 2022). A study conducted by Buday (1995) compared the effects of two conditions (music and speech vs rhythm and speech) examining the imitation of signed and spoken words. The results showed that the higher number of correctly imitated both signed and spoken words was learned in the music and speech condition when compared to rhythm and speech condition. Another study compared the effect of musical training, speech training and no training on verbal production in autistic children where it was shown that both music and speech training significantly increased participants' verbal production

(Lim, 2010). The authors noted that autistic individuals with greater symptom severity showed greater improvement after musical training (songs and pictures of target words), when compared to speech training. Such findings are consistent with previous literature finding greater benefits of musical training in minimally verbal autistic children (Chenausky et al., 2022).

1.4.2 Cognitive abilities

Autistic individuals rely less on their verbal reasoning (Mottron, 2011; Fugard et al., 2011), which in turn creates more activity in the visual-processing network than in that of speech-processing (Gaffrey et al., 2007). Consequently, autistic people tend to outperform controls on abstract reasoning as measured on Raven's Matrices and complete the questions quicker than controls (Soulières et al., 2009). On the other hand, autistic participants score lower than controls on language tasks, where they are verbally instructed (Dawson et al., 2007). Studies reported association between auditory abilities and nonverbal reasoning supporting the idea of preserved pitch processing in autistic individuals with average IQ (Chowdhury et al., 2017). However, some studies reported enhanced pitch processing in a subgroup of autistic individuals independently of intelligence, musical training and experience (Heaton et al., 2008b).

The three subcomponents of working memory are the phonological loop (or verbal working memory), visuospatial working memory (WM), and the central executive branch, which includes the attentional control system (Baddeley & Hitch, 1974; Baddeley, 2000). There are mixed findings in the literature: some studies reported deficits in autistic individuals' verbal WM (Whitehouse et al., 2008) and visuo-spatial WM (Williams et al., 2005) but not in verbal WM (Williams et al., 2005). Nonetheless, both measures are correlated with vocabulary learning and attention (Atkins & Baddeley, 1998; Baddeley, 1992). In addition, some studies reported enhanced pitch processing in autism due to their enhanced pitch memory (Stanutz et al., 2014).

In summary, we controlled for the following confounding variables across all empirical chapters: receptive vocabulary, abstract reasoning, verbal and non-verbal short-term memory, musical training, and language background (native English speakers with no prior knowledge of Mandarin).

1.5 Further implications: Congenital Amusia

One of the most prominent questions in the field of music and language processing is to what extent the two share mechanisms in the brain (Patel, 2008). Individuals with congenital amusia have impaired musical perception and production (e.g., unable to sing in tune) despite having normal intelligence and hearing (Liu et al., 2015), and no brain damage (Peretz & Hyde, 2003). Early research on amusia suggested that this is a domain-specific deficit (affecting music processing only) (Ayotte et al., 2002). However, further research has shown that this may not be the case as some studies found a speech deficit in such individuals as well, arguing a domaingeneral position instead. For instance, Patel et al. (2008) compared speech and non-speech pitch discrimination in amusics and found that 30% of amusics performed worse on the natural speech task when compared to tone analogous. To create more ecologically valid stimuli, Liu et al. (2010) then used smaller pitch excursions and found that controls outperformed individuals with amusia on discrimination, identification, and imitation of statements vs questions differing in their pitch direction in the final word (e.g., This is love./?)., confirming that amusia might be a domain-general deficit.

In language comprehension, the fundamental frequency (F0) plays a crucial role (Miller et al., 2010) in everyday settings (e.g., noisy environments). In non-tonal languages (e.g., English), F0 variation can be a cue for a difference between a statement and a question (Bartels, 2014) whereas in tonal languages such as Mandarin, the lexical meaning depends on the F0 variation (Patel et al., 2010). Previous studies have shown that both tonal and non-tonal listeners show better comprehension with natural than flattened F0 in noisy conditions (Binns & Culling, 2007; Watson & Schlauch, 2008). Liu et al. (2015) explored Mandarin amusics' comprehension abilities in quiet and noisy settings using News-like sentences (Nazzi et al., 1998) while manipulating the F0. The results showed impaired comprehension in individuals with amusia in both quiet and noisy conditions, as well as with both natural and flattened F0.

Studies investigating both neurotypical individuals (e.g., Fadiga et al. 2009) and individuals with amusia (Liu et al. 2010) have demonstrated shared mechanisms between language and music processing. For instance, individuals with amusia are reported to have intonation-processing deficits, which affects their language abilities (Liu et al., 2010) but individual differences present a key factor if such individuals will exhibit difficulties with production or perception (Williamson et al., 2012). Contrary to individuals with amusia, autistic individuals show a relative strength in pitch direction and intonation tasks (e.g., Heaton, 2005) but both individuals with amusia (Zhou et al., 2019) and autistic individuals show atypical integration of syntactic violations (MárquezGarcía et al., 2022). This thesis extends current knowledge production and perception processing in autism, which could also be applied in individuals with amusia but in vice versa order, depending on the task modality.

1.6 Aims of this thesis

The aims of this thesis were conducted throughout four empirical studies and were as followed: **1)** To gain a clearer understanding of non-tonal (i.e., English) speaking autistic individuals' perceptual abilities of foreign pitch (no lexical information) in Mandarin, and to investigate if superior abilities will only be present in a subgroup of autistic individuals. It was expected that autistic participants would show superior discrimination abilities when compared to controls since there was no lexical meaning to process. In addition, if no group differences were found, we expected to identify a subgroup of autistic individuals who would show superior perceptual abilities. **2)** To gain a deeper understanding of linguistic production abilities in autistic individuals. To measure this, a novel Sentence Repetition (SRep) task was designed to incorporate different conditions (spoken vs sung sentences) and different sentence types (e.g., nonsensical vs newslike). It was expected that controls would exhibit a higher accuracy than autistic participants since the sentences were in English (carrying lexical information) but we were also interested to see how different conditions would impact participants' recall, given often enhanced auditory abilities in autism. **3)** To investigate both production and perceptual abilities in autism whilst investigating expectancy in both musical and linguistic domains. It was expected that autistic participants would outperform controls on musical production/perceptual abilities, whereas we expected controls to outperform autistic participants on language production /perceptual tasks. **3a)** To extend current knowledge of the Weak Central Coherence account and to investigate if autistic participants would show "local" completion on a linguistic production task. Overall, it was expected that autistic individuals would produce more local responses than controls, and would have a lower completion score than controls would.

In sum, Study 1 aimed to investigate the perceptual abilities of autistic individuals, expecting superior discrimination abilities of a foreign pitch, compared to controls. This further motivated the design of Study 2, where it was expected that controls would show a higher accuracy on a sentence repetition task, but it was exploratory to see if autistic individuals would show better performance in the sung condition, compared to the spoken condition. Finally, Study 3 aimed to investigate both perceptual and production abilities in parallel across auditory and linguistic domains, whereas Study 3a focused on testing the WCC (Happé, 2005) account and investigating the "local" bias in autistic individuals (see Table 1.2 for further details).

Table 1.2

A summary of research questions, measures, and hypotheses across all studies

Research question	Measure	Hypothesis
Study 1: a) Do autistic individuals show enhanced auditory perceptual abilities? b) Is there a subgroup of autistic individuals who possess exceptional perceptual abilities?	Foreign pitch discrimination tasks: a) Natural speech vs gliding tone analogue b) Lexical tone	a) Autistic individuals will outperform controls on each discrimination task. b) If no group differences are found, there will be a subgroup of autistic individuals who possess exceptional discrimination abilities.
Study 2: Do autistic individuals show impaired linguistic production abilities, and does this vary across different conditions?	Sentence Repetition task, whilst manipulating: a) Content (news-like, story-like, nonsensical sentences) b) Noise (presence/absence) c) Form (speech vs song)	Controls will outperform autistic individuals on the SRep accuracy. It was exploratory to see if and how each group's performance would differ across the conditions.
Study 3: Do autistic individuals show difference in production and perceptual tasks across auditory and linguistic modalities?	Sentence/Melody Completion Task, and Sentence/Melody Perceptual Task (low vs high expectancy conditions)	Controls will produce more "The most frequent" answers on the SCT than autistic individuals. Autistic individuals will produce more "The most frequent" answers on the MCT compared to controls. It was exploratory to see if any differences would occur on the perceptual tasks across modalities.
Study 3a: Do autistic individuals show a "local bias" on a sentence production task	Sentence Completion Task (Booth & Happé, 2010)	Autistic individuals will produce more "local" responses compared to controls.

2 Are autistic individuals better at tone and intonation perception in a tone language compared to typically developing individuals?

2.1 Introduction

Pitch perception plays an essential role in both speech and music perception (Lee & Hung, 2008; Patel, 2008, p. 20). In music, pitch provides information on whether a vibration sounds either 'high' or 'low' in frequency. In tone languages such as Mandarin, it helps differentiate between various meanings of a specific word (e.g., /ma/ means 'hemp' with a rising tone and 'to scold' with a falling tone) (Clark et al., 1990; Jiang et al., 2012). In British English, pitch signifies different intonations, such as a statement versus a question (Grabe, 2004). Pitch processing is required for both musical understanding and spoken language understanding. Autistic individuals are of particular interest in studying music and language in parallel since one of their core symptoms is communication deficits (APA, 2013) whilst a broad range of the literature reports enhanced perceptual abilities in the auditory domain in autism (Bonnel et al., 2003; Mottron et al., 2000).

Pitch perception in autism

There has been an increasing number of studies investigating auditory and speech processing in autistic individuals as these individuals often have deficits in speech processing (e.g., Schwartz et al., 2020; Stevenson et al., 2014). However, findings of auditory processing are often mixed (e.g., Heaton, 2005; Bonnel et al., 2003; Mottron et al., 2000). So far, it has been reported that autistic participants could have intact (Järvinen-Pasley & Heaton, 2007), diminished (Lepistö et al., 2006) or enhanced (Jones et al., 2009) auditory processing. Such discrepancy could be explained mainly due to methodological differences (e.g., duration or complexity of stimuli). For instance, in Lepistö et al. (2006) an event-related potential (ERP) paradigm was used where autistic individuals showed diminished hit rates for duration changes for speech pitch only but not for non-speech pitch, whereas Jones et al. (2009) identified only a subgroup of autistic individuals who exhibited exceptional frequency discrimination skills.

The following sections will discuss different empirical evidence on perceptual abilities in autism. This relates to the following topics: pure tone versus complex tone processing, low versus highlevel processing, local versus global processing, and other factors that may influence perceptual abilities (e.g., musical training, and language background).

Pure tones versus complex tones perception in autism

Behavioural studies on pure tone perception have found that autistic individuals have increased tone sensitivity. For example, Bonnel et al. (2003) asked participants to discriminate between 'same vs different' pure tones and to categorize tones as either 'low' or 'high'. The results have shown superior pitch processing among autistic individuals on both measures. More research suggested that compared to their controls, autistic individuals as a group had a better pitch memory (Heaton et al., 2008b; Heaton, 2003) and was better at identification and discrimination of pitch changes in simple pure-tone stimuli (a non-speech material) (Bonnel et al., 2010; O'Riordan & Passetti, 2006). These results emphasise a relative strength in autistic individuals to perceive pitch changes especially non-speech stimuli which does not carry any lexical information.

Besides pure tones processing, complex musical stimuli processing has also been explored in autistic individuals. The findings have been mixed; reporting either intact (Järvinen-Pasley & Heaton, 2007; Heaton, 2005) or superior (e.g., Järvinen-Pasley et al., 2008a; Heaton, 2003) processing of musical material for pitch discrimination. For instance, in a study done by JärvinenPasley and Heaton (2007), participants were separated into three groups: High Functioning Autism (HFA), Asperger syndrome, and controls. The participants were asked to discriminate pitch in speech–speech, speech–music and music–music conditions. There were no differences between any of the groups, suggesting intact musical pitch processing in autistic individuals. The same pattern of results was found in another study done by Heaton (2005) where autistic children had intact pitch contour discrimination. However, studies done by Järvinen-Pasley et al. (2008a) and Järvinen-Pasley et al. (2008b) found enhanced perceptual processing of speech in autistic individuals, compared to controls.

There are several plausible explanations for such differences in studies' results. For instance, Mottron et al. (2000) were stricter about the exclusion criteria where all participants had a normal full-scale IQ (>80) which was not the case for either Järvinen-Pasley et al. (2008b) or the study done by Foxton et al. (2003). Since pitch performance and nonverbal IQ are highly correlated (Heaton et al., 1998; Chowdhury et al., 2017), it is plausible that studies' results which did not match their groups on the IQ have been biased by this confounding variable. In addition, even when reporting enhanced pitch processing in autism, authors noted that controls processed speech semantically, which was not the case for autistic individuals (Järvinen-Pasley et al., 2007). This supports previous research finding that autistic individuals exhibit superior perceptual abilities when processing non-speech stimuli only (no lexical information) (Yu et al., 2015).

Association between high-level and low-level pitch performance

Perceiving acoustic patterns can be explained through hierarchical processing (Warren & Griffiths, 2003; Wessinger et al., 2001) where 'lower-level' tasks are considered to be simpler (e.g., fundamental frequency) whereas 'higher-level' tasks require integration of 'lower-level' auditory information (e.g., speech in noise) (Nahum et al., 2008). Germain et al. (2019) noticed that none of the previous studies investigated both low and high levels of perceptual processing. Thus, the main aim of the study was to explore the relationship between differences in low-level pitch direction (PD) capability (pairs of tones that differed in pitch and were presented at different temporal rates) and global-local (GL), i.e., high-level processing (three-tone triplet sequences forming nine harmonic tones) between autistic and typically developed children. The results showed that autistic participants had intact but not enhanced performance on both tasks. Such results are in line with similar studies (Bonnel et al., 2010; Mayer et al., 2016) investigating other factors which may influence performance in the autism group, such as age or diagnostic severity. For instance, although age did not have impact on either of the groups' performance, controls had a stronger positive relationship between GL performance and age when compared to autistic participants. This relationship between GL and age might be a cue for age effects in higher-level auditory perceptual tasks in controls but not in the autistic population (Mayer et al., 2016). In addition, Bonnel et al. (2010) found enhanced pure-tone pitch discrimination only in autistic participants who showed larger diagnostic severity (e.g., language delay). Finding that the stimulus rate had a statistically significant impact on performance on GL tasks is in line with previous studies showing a positive relationship between auditory and visual processing in autistic individuals (Bouvet et al., 2014; Stevenson et al., 2014).

Theories of perception in autistic individuals

There are two main perceptual theories which differ in their interpretations of perceptual functioning in autistic individuals. The first one is the Weak Central Coherence (WCC) theory (Frith, 1989; Happé & Frith, 2006) which suggests that autistic individuals tend to process information in a detailed way rather than a global way, unlike typically developed people. Thus, autistic individuals can show superior performance on tasks where the "featural" (i.e., processed in parts rather than as a whole) processing style can be beneficial (Happé, 1999). The WCC can be observed at both "low" and "high" levels (Happé, 1996, 1997) of processing, where "low" presents low-level integration (e.g., visual tasks) and "high" presents high-level integration (e.g., making inferences between sentences). Previous studies reported enhanced performance in autistic individuals on embedded figures task and the block design tasks (Shah & Frith 1983, 1993; Happé et al. 2001), and enhanced pitch processing (Bonnel, 2003; Heaton, 2003; Järvinen-Pasley et al., 2008) but impaired ability to make inferences in the text (Happé, 1997; Jolliffe & Baron-Cohen 1999). Thus, it could be said that autistic individuals tend to show superior perceptual functioning on tasks where they can rely on "features" whereas on the higher-level tasks, where they need to combine parts into a whole, they show impaired performance. In an extensive review of behavioural and electrophysiological studies on auditory processing and speech perception, it was confirmed that autistic individuals tend to have either intact or enhanced processing of acoustic features (i.e.., “local”) while their “global” processing is less universally impaired (Haesen et al., 2011).

An alternative view to the WCC is the theory of Enhanced Perceptual Functioning (EPF; Mottron & Burack, 2001; Mottron et al., 2006). According to the EPF model, autistic individuals show enhanced perceptual functioning namely on the ‘low-level’ cognitive tasks while also having unimpaired performance on ‘high-level’ tasks due to their abnormally high involvement of perceptual functioning. This is in line with studies showing enhanced local processing at no expense of global processing (Plaisted et al., 2003) on both musical (Applebaum et al., 1979; Foxton et al., 2003) and linguistic pitch processing tasks (Järvinen-Pasley & Heaton, 2007).

Effects of confounding variables on performance in discrimination tasks

In the following sections, some factors that influence performance on discrimination tasks will be described. Namely, it will be discussed how tone speaking autistic individuals may show similar abilities to musicians, and how this relates to a rather high occurrence of possessing Absolute Pitch in autism. In addition, some studies found only a subgroup of autistic individuals who show exceptional discriminatory abilities, which in turn, were related to language delay (Jones et al., 2009), so this factor will be discussed as well. Finally, cognitive abilities such as short-term memory will also be discussed since some studies reported that autistic individuals may possess superior pitch memory (Heaton, 2003).

Language Background, Absolute Pitch, and Musical Training

Burnham et al. (1996) reported that English-speaking children perceive non-native segmental contrasts (vowels and consonants) better than non-native lexical tone contrasts, while Englishspeaking adults perceive non-native tonal contrasts better than non-native segmental contrasts. For instance, in a study done by Halle et al. (2004), Taiwanese (tonal) and French (non-tonal) listeners were asked to identify and discriminate utterances in Mandarin. Although Taiwanese listeners outperformed their French counterparts, the findings suggested that French listeners were not completely ‘deaf’ to tonal variations. The results are in line with other studies reporting tonal speakers' advantage when perceiving Mandarin tones (Wu & Lin, 2008) and discriminating Taiwanese Southern Min tones (Sun & Huang, 2012), compared to English speakers with no prior knowledge of tonal languages. A doctoral thesis conducted by Lu (2016) demonstrated equal perceptual abilities between autistic children and their TD peers in comprehending and discriminating Mandarin tones. However, the main difference between the groups was in the type of errors they made where autistic children made more errors when presented with the tone 2-3 contrast (a high-rising pitch contour vs low falling-rising pitch contour, respectively) (Chao, 1948). In addition, it was also found that autistic children perceived nonsense words as pure tones, being less affected by the lexical information.

The capability of having an Absolute Pitch (AP) – identifying or re-creating a given musical note independently of a reference tone, has been positively associated with tonal language speakers (Deutsch et al., 2004; Deutsch et al., 2006; Deutsch et al, 2009; Deutsch et al., 2013) and autistic individuals or those with high autistic traits (Mottron et al., 1999; Brown et al., 2003; Heaton et al., 2008a). Such association is consistent with the above results (Deutsch et al., 2004), and previous studies confirmed that the advantage that tonal speakers show in perceiving native stimuli comes from their tonal language background, rather than the musical training (e.g., Stagray & Downs, 1993; Xu et al., 2006; Halle et al., 2004).

Only a small percentage of musicians possess AP but there is a rather high prevalence of AP ability among autistic individuals (Brown et al., 2003). In addition, some studies reported a higher degree of autistic traits in APs than in non-APs, and non-musicians (Dohn et al., 2012). Interestingly, there is also a higher number of autistic individuals who speak a tone language (e.g., Mandarin) and possess AP when compared to autistic individuals who speak a non-tonal language (e.g., English) (Deutsch et al., 2006).

Turning to non-tonal speakers, Lee and Hung (2008) noted that non-native listeners with musical backgrounds tend to identify lexical tones better than those without musical backgrounds. In a group of American-English speakers greater musical training was associated with better discrimination in identifying the four distinctive tones in Mandarin (Gottfried et al., 1997). Another study compared English and Mandarin musicians' and non-musicians' performances in categorical contour, reporting that tone language background increases sensitivity to melodic contour (Bradley, 2012).

Autism symptom severity, language delay and cognitive abilities

Some studies found enhanced pitch discrimination abilities only among autistic participants with delayed speech onset (Heaton et al., 2008b, Jones et al., 2009). For instance, Bonnel et al. (2010) tested two groups of autistic individuals: the ones with autism (i.e., with language delay) and the ones with Asperger's (first single words before 24 months and first two-word phrases before 33 months) and compared them to TD individuals. It was found that superior pitch discrimination was only present among individuals with autism, but not among individuals with Asperger's. Enhanced pitch discrimination for pure tones was also found in a study by Jones et al. (2009). However, this was only for a subgroup of autistic adolescents that had higher IQs and delayed onset of first words. Therefore, it is plausible that superior pitch processing is related to a subgroup of autistic individuals with significant language problems, which in turn, is associated with greater symptom severity (Thurm et al., 2015). In this longitudinal study examining language development and symptom severity, once the nonverbal IQ was added to the model, change in severity (from T1 to T2) no longer predicted continuous expressive language (Thurm et al., 2015).

Similarly, Emmons et al. (2022) investigated maintaining and switching attention by comparing how different cues (location, voice, location, and voice) together might have an impact on participants' performance. Overall, controls were more accurate than autistic participants, whereas autistic individuals performed equally well using either local or voice cues, but their performance was the most accurate when using both cues. Due to the difference in IQ scores between the groups, a linear regression analysis was computed to see if the IQ score would be a predictor of overall performance. The results showed that the IQ was not a statistically significant predictor of overall performance in any of the groups.

Short-term memory

Both typically developed and autistic individuals tend to recall information more accurately from their short-term memory rather than long-term memory (Baddeley, 1986). Although controls outperform autistic individuals on verbal short-term memory tasks (Poirier et al., 2011), this has been less consistent on tasks that require pitch or music processing, where autistic individuals outperform controls (e.g., Jones et al., 2009). Some studies suggested that enhanced pitch processing in autistic individuals could be due to their enhanced pitch memory capacity (Heaton, 2003), rather than possessing a superior ability to discriminate pitch per se, especially if the stimuli involve their special interests (Pring, 2008). Schwartzberg and Silverman (2012) found better recall in controls than in autistic participants across all conditions (speech, rhythm, pitch, and accompaniment) of visual information. Nonetheless, although not statistically significant, autistic participants had a more accurate recall in the music condition than in the speech condition. This is in line with studies reporting that music enhances recall (Taylor & Dewhurst, 2017) where autistic individuals show enhanced short-term and long-term memory in melodic contexts (Stanutz et al., 2014).

Current study

What remains unclear and has not yet been well explored, is how English (non-tonal) speaking autistic individuals would discriminate foreign tones and speech in a tonal language (i.e., Mandarin) whilst controlling for confounding variables such as short-term memory. Since the literature consistently suggests that tone language speakers are significantly faster and more accurate at discriminating intact speech items on the basis of pitch contour when compared to nontonal speakers (Stevens et al., 2011), it was of interest to explore how accurately would non-tonal speaking autistic individuals discriminate foreign stimuli, without processing any lexical information. The current study extends previous knowledge on foreign pitch discrimination in autism or its relation to autistic traits. More specifically, Mayer et al. (2016) only used receptive vocabulary as a background measure, whereas Iao et al. (2018) tested students using foreign speech stimuli only. In the current study, to avoid any group differences on related background measures that in turn may have an impact on experimental task performance, groups were matched on all background measures. This study adds novelty to the field as multiple background measures were considered, and participants completed three experimental tasks which varied in their complexity across two domains (foreign speech vs non-speech).

2.2 Aims

To our knowledge, no prior study examined the differences between autistic individuals and controls in non-tonal language speakers (English) on tonal language stimuli (Mandarin) while controlling for related variables: *musical training, autism diagnosis, low-level psychophysical pitch thresholds, receptive vocabulary and abstract reasoning, and non-verbal cognitive abilities, and verbal and non-verbal short-term memory*, while testing both speech and non-speech perceptual abilities. In sum, the present study aimed to explore the relationship between musical and linguistic pitch processing by addressing the following questions: (1) Do English-speaking autistic individuals outperform TD individuals on tone and intonation perceptual tasks in foreign pitch? (2) If no group differences occur on main experimental tasks, will there be a subgroup of autistic individuals who exhibit superior pitch discrimination abilities? 3) Are pitch thresholds in both groups related to performance on tone and intonation perceptual tasks?

It was predicted that autistic individuals would outperform controls in detecting the differences on all Discrimination tasks. If there were no group differences, it was predicted that there would be a subgroup of autistic individuals who would exhibit superior discriminatory abilities. In addition, it was also predicted that there would be a statistically significant impact of pitch change detection, and pitch direction tasks on the main experimental Discrimination tasks. In other words, we expected these measures to be negatively associated; the lower the pitch thresholds, the better the performance.

2.3 Method

Participants

Participants were recruited through the existing database, and through various advertisements (e.g., social media, schools, SONA). Participants were excluded from the control group if their score fell within the ASD range on The Autism Spectrum Quotient questionnaire (AQ) (BaronCohen et al., 2001), which was used as a pre-screening tool.

Participants were 42 controls (13 males) between 14 and 56 years of age (M= 26.05, SD= 10.19) and 21 autistic individuals (10 males) between 13 and 58 years of age (M= 32.38, SD= 16.02). All participants were British English native speakers. Participants in the control group were healthy individuals with no hearing or speech problems, whereas all autistic participants received a formal diagnosis of autism or Asperger syndrome by a qualified clinician using DSM-IV or DSM-5 criteria (APA, 1994). Six (2 females) clinical diagnoses were confirmed by ADOS-2 examinations administered (by AV) for the purposes of the study. The rest of the autistic participants was not assessed on ADOS-2 due to the COVID-19 pandemic and its restrictions, but their diagnosis was pre-screened using the AQ. Participants were matched as a group on both verbal (Receptive One-Word Picture Vocabulary Test-4; ROWPVT-4, Martin & Brownell, 2010/2011) and nonverbal abilities (Raven's Standard Progressive Matrices Test, Raven et al., 1989). It was required that all participants reach a threshold on receptive vocabulary (standard score of 70) and abstract reasoning (score of at least equal or larger than the 5th percentile) to take part in the study. Participants who failed to reach either of these requirements were excluded from the study. Other background measures included verbal and nonverbal short-term memory and musical training. Participants' nonverbal short-term memory span was measured using the Corsi block-tapping task (Kessels et al., 2000), and The forward digit span task was used to assess participants' verbal short-term memory (Wechsler, 2003). Musical training was measured as the total number of years of reported experience, cumulative across all instruments and voice (Pfordresher & Halpern, 2013). All participants had normal hearing in both ears, with pure-tone air conduction thresholds of 25 dB HL or better at frequencies of 0.5, 1, 2, and 4 kHz.

Written informed consent was obtained from all participants, and the study was approved by the University Research Ethics Committee (UREC 16/37) at the University of Reading (Great Britain). For participants, whose age was less than 16, a parent's consent was required as well.

Materials

Intonation discrimination task in Mandarin

Intonation stimuli were recorded by a 20-year-old female student at Goldsmiths, University of London, whose native language is Beijing Mandarin. The recordings were made in soundproof booth using Praat, with a 44 100 Hz sampling rate (Boersma, 2001). Intonation stimuli comprised 20 statement-question pairs that had the same word sequence but varied in intonation. Each word was 3-7 syllables long and was comprised of High/Falling tones only. All the above materials have been adopted from Liu et al. (2012). On average, the task took about 5-10 minutes to complete.

Lexical tone discrimination task in Mandarin

The stimuli were comprised of 72 disyllabic pairs, of which 36 were real words in Mandarin, whereas the other 36 were non-words. The initial syllable differed in half of the pairs, whereas the second syllable differed in the other half. Each stimulus pair appeared in both "same" and "different" condition, leading to a total number of 144 trials. The stimuli were randomized and presented to each participant in a different order, with 750 ms interstimulus interval and 1500 ms intertrial interval. The duration of the stimuli was normalised to 450 ms, with intensity normalised at 65 dB. On average, the task took about 5-10 minutes to complete.

Pitch Thresholds in Speech and Music (PTSM): /ma/ and piano tone analogues

In this task participants completed identification of pitch direction in the syllable /ma/ and piano tone, each lasting about 7-15 minutes. Participants heard two speech syllables (“ma-ma”) or two piano tones at a time, with one having a higher pitch than the other, and then they were asked to report which sound has a higher pitch, the first sound, or the second one. For both stimulus types, there were a standard stimulus of 131 Hz (C3) and 63 target stimuli that deviated from the standard in steps (DF, F0 difference or pitch interval between the standard and target stimuli) of 0.01 (10 steps between 131.08 and 131.76 Hz, increasing by 0.01 semitones in each step), 0.1 (9 steps between 131.76 and 138.79 Hz, increasing by 0.1 semitones in each step), and 0.25 semitones (44 steps between 138.79 and 262 Hz, increasing by 0.25 semitones in each step). Therefore, the smallest pitch interval (DF between the standard and step 1 deviant) between the standard and target stimuli was 0.01 semitones, and the largest pitch interval (DF between the standard and step 63 deviant) was 12 semitones (Liu et al., 2017). The stimuli were adapted from Liu et al. (2017).

Pitch Thresholds in Pure Tones (PTPT): Detection and Direction

In this task participants’ thresholds were measured for pitch change detection and pitch direction discrimination. An adaptive-tracking procedure was used and a 3-interval, 2-alternative forcechoice ‘odd-one-out’ design was implemented. In the pitch direction task, participants were asked to report which tone differed in direction among three gliding tones. The pitch changes always occurred on the first or the last (third) tone. The ‘odd’ one was rising versus falling from the other two (Liu et al., 2010; Liu et al., 2012). In the pitch detection task, participants were asked to report which of the three pure tones (two steady and one gliding) contained a glide. Each tone was 600 ms in duration, and there was a 600 ms interstimulus interval. On average, the task took about 7-15 minutes to complete.

Procedure

For all three Discrimination tasks in Mandarin, the stimuli were played to participants over computer headphones at a comfortable listening volume within a sound attenuated room. The experiment was presented using PsychoPy programme, and all responses were stored as .xlsx files. Participants read the instructions on the screen and had either four (Natural speech/Gliding tone analogues) or eight practice trials (Lexical tones) before the main trials. During testing, participants were asked to judge as quickly and accurately as possible whether a pair of tones or (non-)words were the same or different. Responses were recorded with key presses where number 1 (one) was used for ‘different’, and 0 (zero) for the ‘same’.

In *PTSM* tasks, participants were asked to report which sound had a higher pitch; either the first, or the second one. The procedure was the same for both speech (/ma/) and music (piano analogues tone) stimuli. Both tasks measure the smallest pitch difference that can be detected by the participant. In the beginning, the pitch differences are large and easy to detect but the task was programed in a way that it automatically tracks participant’s performance, so the trials became more difficult throughout the task. Participants had to have 100% correct performance on Practice trials to begin with the Main trials. Participants were sitting away from the screen and reported their answers aloud to the experimenter, who was selecting the answers on their behalf. On average, each task took around 7 to 15 minutes to complete. The order of the two tasks was counterbalanced across participants.

Finally, during the Detection *PTPT* task, participants heard three consecutive sounds where one of them would be an ‘odd-one-out’. Such a sound contained a glide (either up or down) and the other two were flat (monotones), so participants were required to *detect* the odd-one-out. The “odd-one-out” was placed in either the first or the last position. The sounds that are the “odd-oneout” started out large (easy to detect) but would get smaller (harder to detect) throughout the task. In the Direction PTPT task, participants heard three consecutive sounds. All sounds were gliding tones but two of them would go in one *direction* and the other would go in the opposite direction of the other two. The “odd-one-out” was placed in either the first or the last position. The participants were asked to report the gliding sound that they thought had the opposite *direction*, when compared to the other two sounds. Both PTPT tasks were performed using Matlab (MATLAB, 2010) and the experimenter selected participants’ responses on their behalf to make sure that participants were paying attention to the task (Horváth et al., 2009). There were four practice trials and 14 reversals in total. To prevent participants’ fatigue, regular breaks (e.g., 5-10 minutes) were offered in between tasks, as requested.

2.4 Results

Descriptive data

All participants were pre-screened on both receptive vocabulary and abstract reasoning to take part in the study. Due to a large amount of data collected, including background measures, and experimental tasks, participants whose data was missing for specific tasks were excluded in the further analysis of that specific measure. In addition, participants’ autistic traits were measured using the Autism Quotient (AQ) (Baron-Cohen et al., 2001). The groups did not differ on any of the background measures, expect for the AQ scores where autistic individuals had significantly higher autistic traits, when compared to controls. The descriptive data for background measures can be found in Table 2.1, and in Table 2.2 for experimental measures.

Table 2.1

Participants' mean scores on pre-screening measures

	ASD (*n* = 21)		TD (*n* = 42)			
Male: Female	10:11		13:29			
Background measure	*M*	*SD*	*M*	*SD*	*t*	*p*
The AQ score	38.4	6.86	16.2	8.96	9.72	< .001
Vocabulary	169	12.82	175.5	6.71	0.03	.97
Raven's raw score	51.27	5.46	52.9	4.23	0.23	.64
Musical Training	4.63	6.32	5.12	6.26	-0.29	.77
Digit span	6.84	1.68	7.12	1.36	-0.98	.33
Corsi	6.05	1.58	6.50	1.45	-1.08	.28

Table 2.2

Participants' mean scores across discrimination tasks

Group	Stimuli	*N*	*M*	*SD*
ASD	Natural speech	21	2.31	0.76
	Gliding tones	21	2.71	0.67
	Lexical	21	2.44	0.89
TD	Natural speech	42	2.43	0.71
	Gliding tones	42	2.73	0.57
	Lexical	42	2.36	0.89

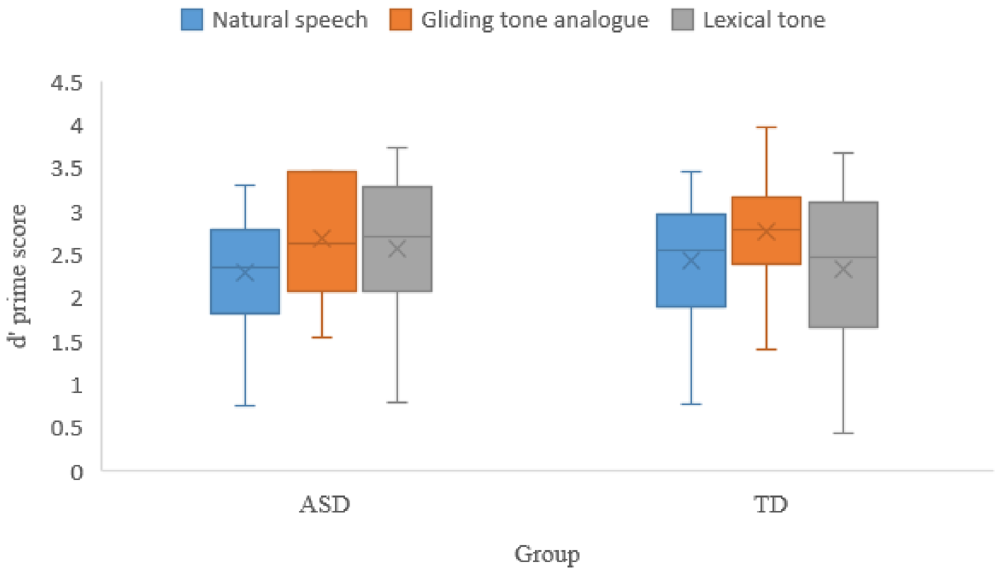
Analysis of variance (ANOVA)

ANOVA analysis was conducted using SPSS software. Participants' results were scored using a formula in Excel to calculate a d' score (Macmillan & Creelman, 1991). Hit was scored when the pair of stimuli was 'different' and participant's response was 'different', whereas a false alarm was scored when the pair was 'same', but participant's response was 'different'. Since Mauchly's test of sphericity was statistically significant (p<0.001), the results from Within-Subjects (Stimuli: gliding tone analogue vs natural speech) will be interpreted using the Greenhouse–Geisser correction. Data obtained from 21 autistic participants and 42 controls (mixed ANOVA, Group: between subjects, Task (natural speech vs gliding tone analogue): within subjects) showed that there was no statistically significant difference between the groups on gliding tone analogues' performance, when compared to natural speech, F (1,61) = 0.22, p = .65, η_p^2= .005.

In addition, the results indicated comparable performance between the groups (one-way ANOVA, Group: between subjects), F (1,61) = 0.12, p = .73, η^2 = .002) on the lexical tone discrimination task. However, there was a statistically significant impact of the stimulus type where both groups performed better at gliding tone analogues (M = 2.73, SD = 0.60) when compared to natural speech (M = 2.39, SD = 0.73), F (1,61) = 16.73, p< .001, η_p^2 = 2.15. Finally, the interaction between Group and Stimuli was not statistically significant, F (1,61) = 0.32, p = 0.57, η_p^2 = 0.95. Details can be found in Figure 2.1.

Figure 2.1

Participants' performance on all three Discrimination tasks



Correlation analyses

PTSM and Discrimination tasks

To test if Discrimination tasks' performance would be related to lower-level pitch thresholds tasks, Pearson's correlation was used. A statistically significant and negative relationship was found between natural speech, and PTSM /ma/, *r* (60) = -.26, *p* = .04, as well as between gliding tone analogous and PTSM /ma/, *r* (60) = -.36, *p*< .001. The strongest relationship was found between Lexical tone discrimination performance, and PTSM /ma/, *r* (60) = - .53, *p*< .001. The same pattern of results was found for the relationship between natural speech, and PTSM piano analogues, r (60) = -.36, p< .001, gliding tone analogous, and PTSM piano analogues, *r* (60) = -.41, *p* = .001, and Lexical tone discrimination performance, and PTSM piano analogues, *r* (60) = -.51, *p*< .001. The results are shown in Figures 2.2, 2.3, 2.4 and 2.5.

Figure 2.2

Pearson's correlation between Discrimination tasks (Gliding tone analogues vs Natural speech) and PTSM /ma/

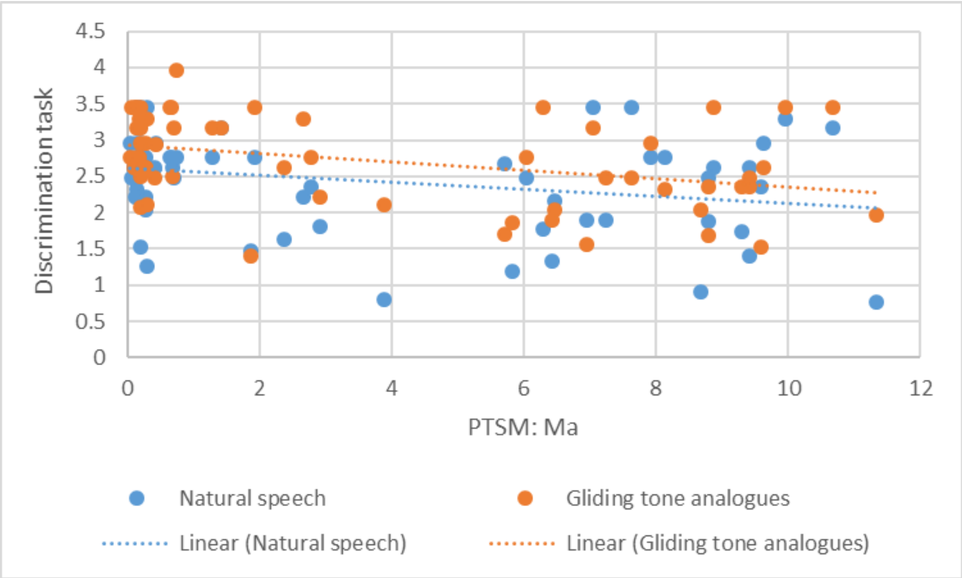


Figure 2.3

Pearson's correlation between Discrimination tasks (Gliding tone analogues vs Natural speech) and PTSM piano analogue

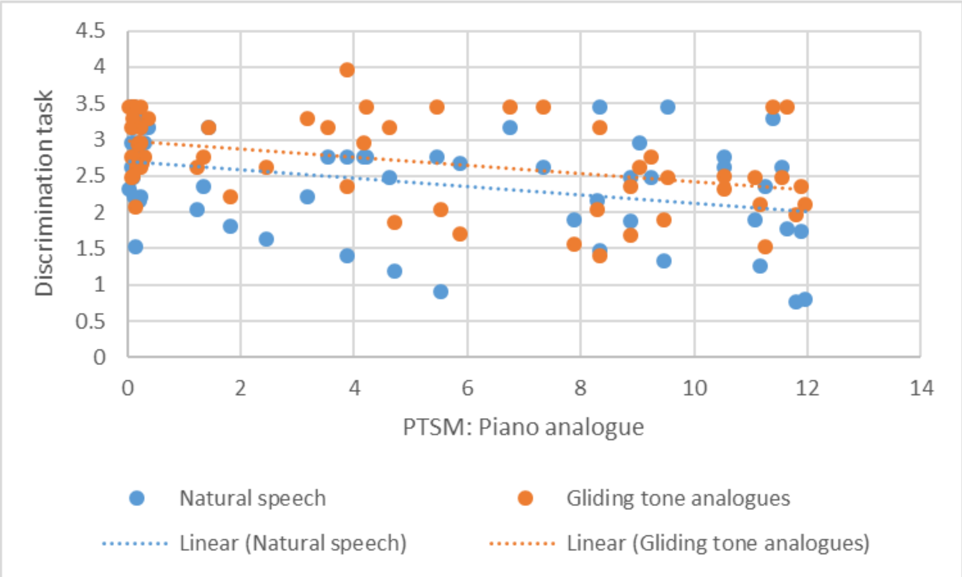


Figure 2.4

Pearson's correlation between Lexical tone discrimination task and PTSM /ma/

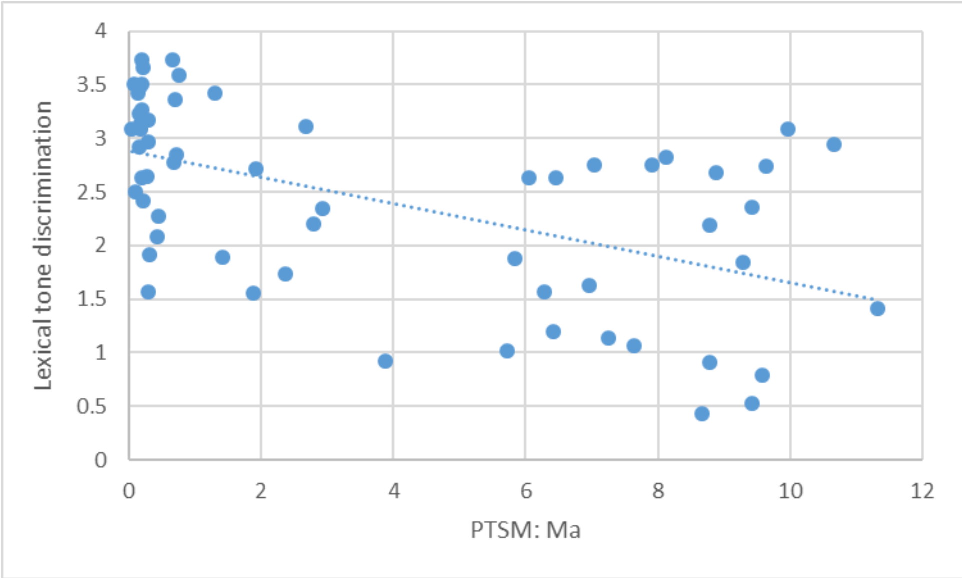
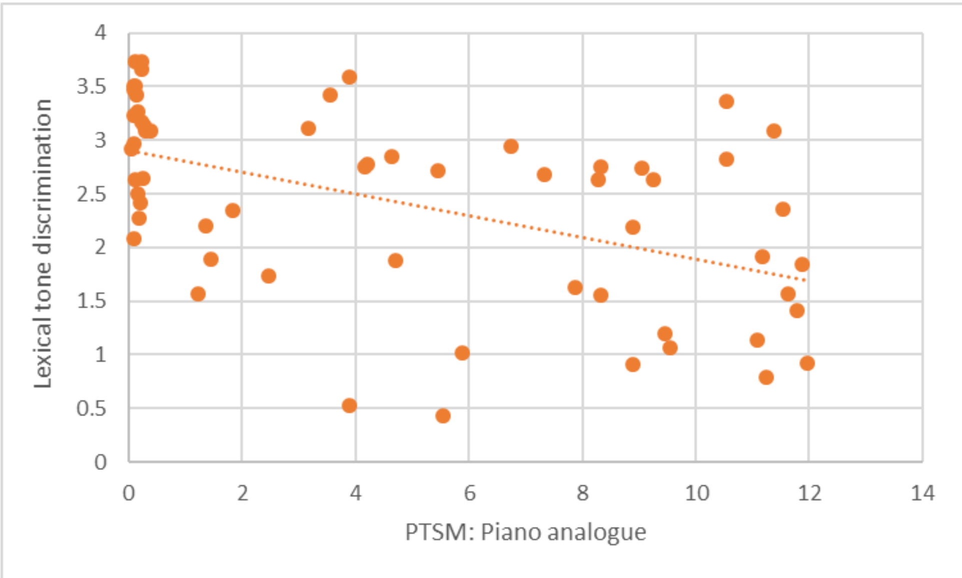


Figure 2.5

Pearson's correlation between Lexical tone discrimination task and PTSM piano analogue



PTPT and Discrimination tasks

A statistically non-significant relationship was found between natural speech, and Detection, *r* (57) = - .05, *p* = .70, whereas this relationship was marginally significant between gliding tone analogous and Detection, *r* (57) = - .26, *p* = .05. The relationship between Lexical tone discrimination performance and Detection was not significant either, *r* (57) = - .19, *p* = .18. Conversely, the relationship between natural speech, and Direction was found to be statistically significant, *r* (62) = - .45, *p*< .001, as well the one between gliding tone analogous and Direction, *r* (62) = - .31, *p*< .05. The relationship between Lexical tone discrimination performance, and Direction was statistically significant as well, *r* (62) = - .42, *p*< .005. The results are shown in Figures 2.6, 2.7, 2.8 and 2.9. Participants' mean scores on both PTPT and PTSM tasks can be found in Table 2.3.

Table 2.3

Participants' mean scores on PTSM and PTPT tasks

Group	Pitch Threshold Task	*N*	*M*	*SD*
ASD	PTSM Piano analogues	19	4.37	4.63
	PTSM Ma	19	3.63	4.24
	PTPT Direction	20	0.64	0.86
	PTPT Detection	18	0.21	0.14
TD	PTSM Piano analogues	41	4.99	4.37
	PTSM Ma	41	3.81	3.71
	PTPT Direction	42	0.27	0.21
	PTPT Detection	38	0.18	0.10

Figure 2.6 .

Pearson's correlation between Discrimination tasks (Gliding tone analogues vs Natural speech) and PTPT Direction

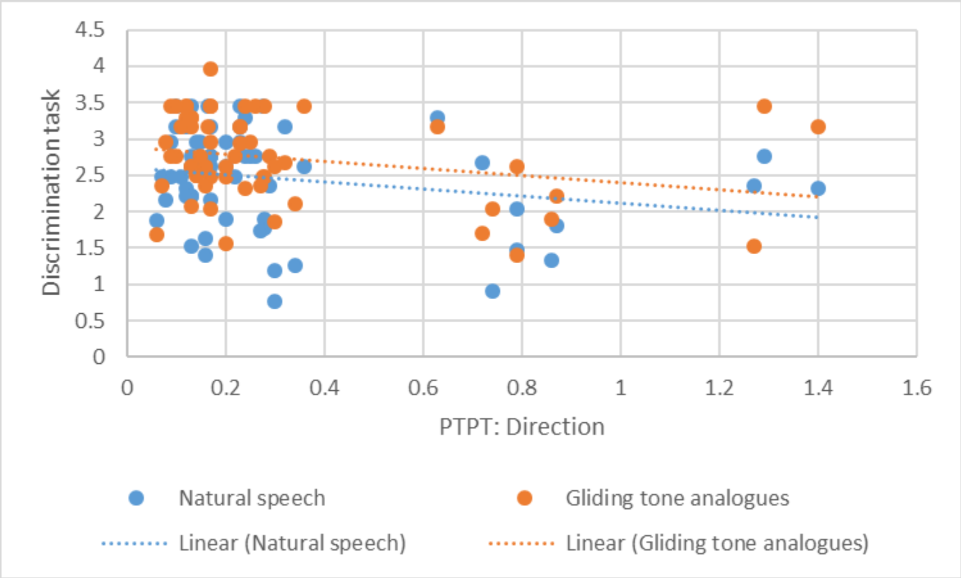


Figure 2.7

Pearson's correlation between Discrimination tasks (Gliding tone analogues vs Natural speech) and PTPT Detection

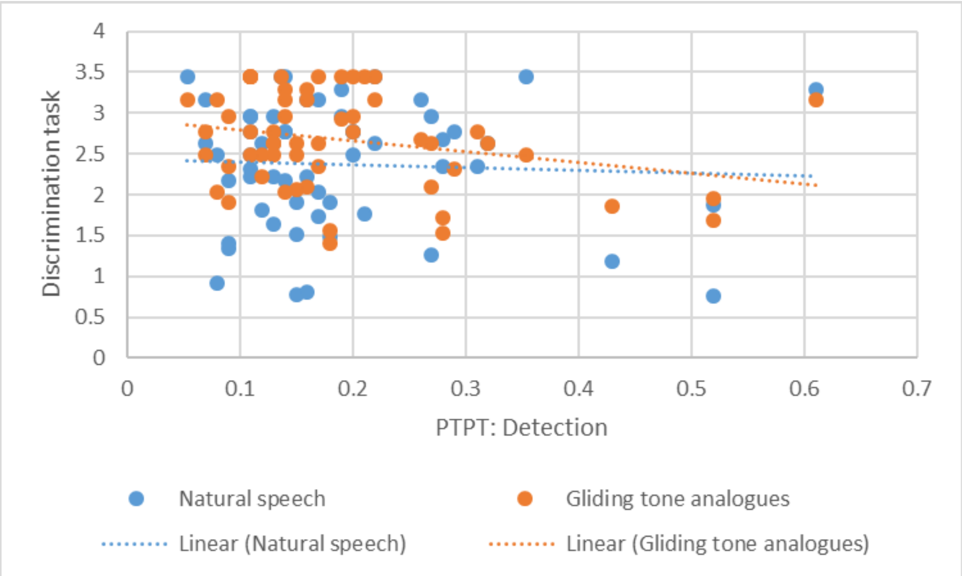


Figure 2.8

Pearson's correlation between Lexical tone discrimination task and PTPT Direction

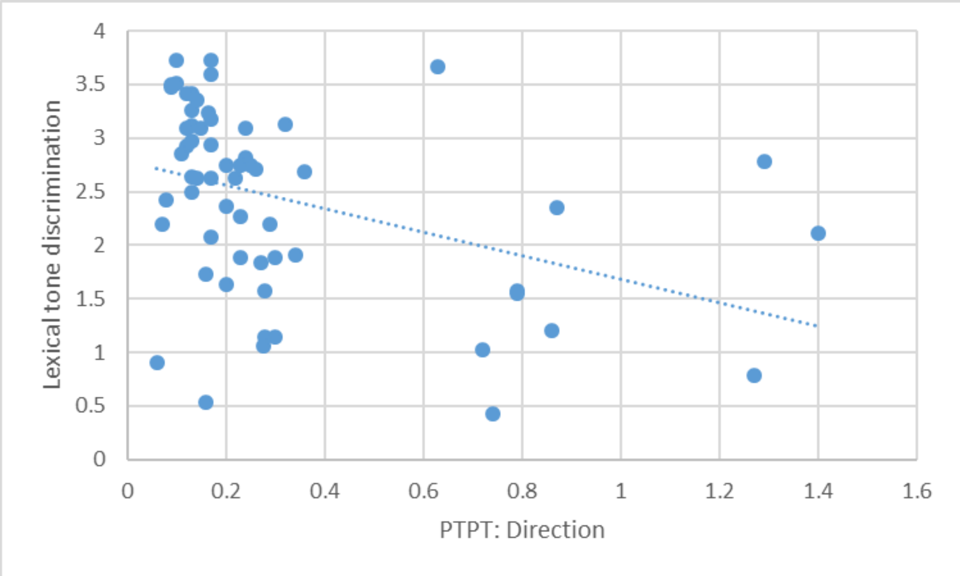


Figure 2.9

Pearson's correlation between Lexical tone discrimination task and PTPT Detection

Subgroup analysis

As previously discussed, some studies reported enhanced perceptual abilities only in a subgroup of autistic individuals (Heaton et al., 2008b; Jones et al., 2009). Therefore, it was of interest to see if group mean scores were masking a small subgroup of autistic participants who are exceptionally good at discriminating Mandarin tones and/or intonation. In this case, the larger the individual's mean score, the better the discriminatory abilities. To identify a subgroup of exceptional discriminators in both groups, Jones et al. (2009) used a threshold score that was 1.65 SD larger than the mean of the control group. In the current study, no differences in any task (natural speech, gliding tone analogue, or lexical tone) emerged between autistic individuals and controls using this criterion. Therefore, we did not identify a subgroup of autistic individuals who possess exceptional discriminatory abilities of the foreign pitch.

2.5 Discussion

The present study investigated whether there would be any differences between autistic individuals and their controls on discrimination of Mandarin tones, and if there would be a statistically significant relationship between lower-level pitch thresholds' performance, and Discrimination tasks' performance. To improve previous studies' limitations, we controlled for potential confounding variables, while employing tasks related to both speech and non-speech perceptual abilities. The findings suggest that there was no difference between the groups on the ability to discriminate Gliding tones analogues when compared to Natural speech in Mandarin. However, there was a main effect of stimulus type where both groups performed better at discriminating pairs in the Gliding tone analogues task. In addition, the results were comparable between the groups on the Lexical tone discrimination task as well. Finally, as predicted, it was found that lower-level pitch thresholds were significantly negatively correlated with Discrimination tasks' performance.

No group difference on any of the Discrimination tasks in Mandarin

We expected to see better perceptual abilities in autistic participants, when compared to controls. However, this was not the case for any of our tasks in Mandarin and there are several plausible explanations for our null results. Firstly, previous studies have emphasised the advantage of tonelanguage-speaking autistic individuals (Jiang et al., 2015) and musicians (Chandrasekaran & Kraus, 2010), whereas we tested non-tonal autistic speakers that were classified as non-musicians. Secondly, the studies that investigated English speakers also found statistically significant impact of musical training where English-speaking listeners who were music majors identified Mandarin tones better than non-majors (Gottfried, 2007). Finally, by controlling for various background measures, we have excluded the possibility of getting a group difference due to any of the confounding variables. Numerous studies have found enhanced perceptual abilities in autism, but when including relevant variables in the model (e.g., verbal/non-verbal IQ), the advantage in the autistic group would either disappear or would be present among a subgroup of autistic children and adults only (e.g., Heaton et al. 2008, Cheng et al., 2017). Jones et al. (2009) found enhanced pitch processing in a subgroup of autistic adolescents, who were characterised by average intellectual ability and delayed language onset. Conversely, participants in the current study were pre-screened on their verbal abilities and had to reach a threshold of 70 (standard score) on a Receptive Vocabulary Test to fully participate in the study. Finally, Emmons et al. (2022) included IQ in the model but did not find it to be a significant predictor for either of their autistic, or TD participants. Instead, the authors pointed out the importance of heterogeneity among autistic individuals who can have a normal/high IQ and still score low on the experimental task, and the other way around.

Gliding tone analogues vs Natural speech

For the discrimination tasks, we differentiated the discrimination of speech and non-speech stimuli, and our results confirmed better discrimination ability at non-speech stimuli, which is in line with studies claiming that non-speech stimuli are easier to discriminate (Burnham et al., 2015).

Another study found that both tonal (Cantonese) and non-tonal (English) speakers were significantly more sensitive to frequency differences between non-speech complex tones when compared to synthesized speech stimuli (Francis & Ciocca, 2003). It is also plausible that the group difference between autistic individuals' performance and their controls' performance disappears when using complex stimuli. Since Gliding tone analogues were also made of complex tones, it could be that autistic individuals excel only on tasks using simple auditory material. This has been well documented in studies which explored pure tones discrimination and categorization abilities, where it was found that autistic individuals had better performance, when compared to their typically developed matches (Bonnel et al., 2003, Heaton et al., 1998, O'Riordan and Passetti, 2006).

Lexical tone discrimination task

In our study, we measured participants' musical training as the sum of both vocal and instrumental musical experiences. As neither of our groups had more than 6 years of musical experience, we could say that they were all non-musicians. Previous studies that investigated lexical tone discrimination focused on comparing musicians' and non-musicians' abilities. Such findings suggest that non-musicians may need more context or additional acoustic cues to help disambiguate the two rising tones (Ong, Wong, & Liu, 2020). Although not statistically significant, autistic participants' mean scores were higher than the controls' mean scores in the Lexical tone task, but the opposite pattern was found for the Natural speech task. This could be since Lexical tones were only 2 syllables long, whereas Natural speech stimuli were comprised of 3-7 syllables, so it could mean that autistic individuals found it easier to discriminate the pairs in the Lexical task.

Relationship between Discrimination tasks in Mandarin and pitch identification/discrimination tasks (PTSM and PTPT)

Most studies of auditory sensory processing have examined either low or high-level processing in isolation, and the first study that investigated tasks on both higher and lower levels in autism was done by Germain et al. (2019). In their study, it was found that stimulus rate had a statistically significant impact on performance on Global-Local tasks, suggesting that high-level pitch performance is strongly associated with low-level pitch performance. This was the case for our results as well, especially for correlations between Lexical task performance, and both PTSM and PTPT tasks. Such a relationship was well examined in amusics (individuals who cannot comprehend music), and the current findings are in line with previous research (e.g., Liu et al., 2016). A study done by Meilleur, Berthiaume, Bertone, and Mottron (2014) investigated the relationship between perception across levels of processing and modalities (audition and vision). The results showed that autistic individuals had superior performance in some perceptual tasks, but the between-group difference in performance depends on the measure used to control for general intelligence. In other words, the performance among autistic individuals seems to be influenced by a specific multimodal perceptual aptitude factor, rather than the general intelligence.

Subgroup analysis

There are several explanations for the discrepancy between the current study's results, and the findings of Jones et al. (2009). Firstly, Jones et al. (2009) specified that enhanced perceptual abilities in autism may only be present within the frequency domain, whereas in the current study, participants were presented with words and non-words in a foreign language, and with statementquestion pairs. Since participants in Jones et al. (2009) only had to specify which sound was 'higher', it could be said that our experimental task was more complex, as participants had to decide if words/non-words and statement-question pairs sounded the same or different, depending on the subtle differences of intonation. This is in line with studies claiming that autistic participants have intact rather than enhanced performance on more complex tasks (e.g., Germain et al., 2019). In addition, autistic individuals' profiles are highly heterogeneous; some studies even reported no group differences on a simple pitch discrimination task (e.g., Foxton et al., 2003). In addition, Jones et al. (2009) noted that a subgroup of autistic individuals with exceptional frequency discriminatory abilities also had a delayed language onset. Future studies should investigate if exceptional discriminatory abilities in a subgroup of autistic individuals are only related to delayed language onset or any other factors, such as pitch memory.

2.6 Limitations and conclusions

For sample size (N = 63) in Study 1 (Lexical tone discrimination task, one-way ANOVA), and a fixed alpha level at.05, post-hoc power calculations revealed that small (f2 = 0.02), medium (f2 = 0.15), and large (f2 = 0.35) group differences were detectable with a with power estimates of 0.05, 0.22, and 0.78, respectively. The same sample was used in the other two tasks (Gliding tone analogue vs natural speech) as part of Study 1 (mixed ANOVA). Using the same fixed alpha level at .05, post-hoc power calculations revealed that small (f2 = 0.02), medium (f2 = 0.15), and large (f2 = 0.35) group differences were detectable with a with power estimates of 0.06, 0.65, and 0.99, respectively. In other words, Study 1 had marginally (Lexical tone discrimination task) adequate power (Gliding tone analogue vs natural speech) to detect large group differences but inadequate power to detect medium or small group differences. Thus, future studies investigating foreign pitch discrimination in autism with a larger sample size are warranted.

In conclusion, we did not find any group difference between autistic individuals and their controls on any of the Discrimination tasks in Mandarin. However, both groups performed better at the Gliding tone analogue task when compared to the Natural speech task. In addition, although some correlations were not statistically significant, all of them were negative suggesting that the better performance was present on the Pitch Thresholds task, the better the performance on the Discrimination tasks. This suggests that there is indeed a relationship between higher and lowerlevel tasks in speech and non-speech. The findings raise the possibility that individual differences in the group of autistic individuals could be the explanation for null findings. As noted by Emmons et al. (2022), some autistic participants could score very well on the IQ and still have low performance on the experimental task, and the other way around: scoring low on the IQ but having intact experimental performance. The difference between the current study and Emmons et al. (2022) is that our groups did not statistically differ on any of the background measures (apart from the AQ), but it is still noted that there could be individual differences not captured by our tasks. Future studies could employ both quantitative and qualitative approaches when analysing the results while investigating group differences in both speech and non-speech stimuli in a foreign language. It would have also been beneficial if our participants were individually matched on all background measures (e.g., age, gender, musical training). Finally, our participants' age range was quite wide, and it would be of interest to investigate developmental trajectories on both higher and lower-level speech and non-speech perceptual abilities, by having three groups of participants: children, adolescents, and adults. This could potentially confirm Mayer et al.'s (2016) findings that reported an increase in pitch discrimination with age in controls but was found to be enhanced in childhood and stable across development in autistic individuals.

3 Is autism associated with differences in song and sentence repetition accuracy?

3.1 Introduction

Language profiles in autistic individuals are highly heterogeneous and complex (Tager-Flusberg, 2004). Some show functional deficits such as issues with pragmatics (e.g., gestures) (Rapin & Dunn, 2003; Baird & Norbury, 2016) or with semantics (meaning of the sentence) (Brook & Bowler, 1992), whereas others tend to have structural language deficits such as delayed phonology on non-word repetition tasks (NWRep) (Kjelgaard & Tager-Flusberg, 2001; Whitehouse et al., 2007) or poor interpretive language abilities (Minshew et al., 1995). As described in the general introduction, despite the heterogeneity in language impairments, autistic individuals tend to have preserved (e.g., Mottron et al., 2000) or enhanced (e.g., Bonnel et al., 2003) musical abilities. This is in line with studies reporting altered brain connectivity in autism (Sharda et al., 2018), whereas the neural processing of music and language is more strongly related in typically developing individuals (Limb, 2006; Patel, 2011).

Often impaired comprehension abilities coupled with enhanced musical abilities in autism could mean that autistic individuals could benefit from musical cues/information in linguistic tasks. This is supported by the studies finding that music intervention enhances communication skills (Zoller, 1991; Sharda et al., 2018), verbal IQ (Bettison, 1996) and vocabulary comprehension in autistic individuals (De Vries et al., 2015). Some studies even reported that autistic individuals could use music as a highly effective mnemonic for learning and recall (Deutsch, 1982; Janata et al., 2002). For instance, Buday (1995) found higher accuracy of signs and spoken words' recall in a music condition (sung text) when compared to rhythmic condition (words spoken rhythmically) in autistic children. Indeed, neuroimaging studies have found that functional systems for speech and song processing are more engaged during the presentation of song compared to speech stimuli in autistic participants (Lai et al., 2012; Sharda et al., 2015).

Apart from the form (speech vs song), it seems that the type of the content also influences comprehension and recall accuracy. For instance, Mar et al. (2021) reported that narrative (i.e., stories) texts are more easily understood and better recalled than expository (i.e., essays) texts.

Another study investigated sentence comprehension on semantic and world-knowledge sentences (Groen et al., 2010). Although no differences in comprehension accuracy between controls and autistic individuals occurred, the autism group showed abnormally reduced left inferior frontal region activity upon integrating social information (speaker characteristic such as gender). Given that communication deficits are one of the core symptoms of autism (APA, 2013), other researchers also explored social vs non-social stimuli and found supporting evidence for better integration of non-social information compared to social information in autistic individuals across the lifespan (Elison et al., 2012). A meta-analysis conducted by Brown et al. (2012) confirmed that autistic individuals are less able to comprehend highly social texts than less social texts, although autism diagnosis does not universally predict comprehension deficits.

Turning to everyday situations, where the environment is often noisy, comprehending speech may be especially demanding for autistic individuals. For instance, Alcantara et al. (2004) investigated sentence recall using different noise levels. The results have shown that controls were more successful in repeating the sentences when compared to the autism group. Interestingly, controls were also better able to take advantage of temporal dips in noise to integrate speech information. Other authors argue that autistic individuals do not have deficient speech-in-noise perception due to their speech hypersensitivity but rather deficient attention which affects their ability to discriminate speech in a noisy environment (Dunlop et al., 2016). Irrelevant of the point of view of what exactly causes autistic people to have difficulties with comprehending speech in noisy environments, studies agree that abilities to understand speech in noisy environments are reduced in autistic individuals (Schelinski & von Kriegstein, 2020; Ramezani et al., 2021).

Investigating Sentence Repetition (SRep) in autism

Sentence Repetition (SRep) tasks are a particularly useful tool that measure participants' comprehension abilities and verbal short-term memory (STM), especially in clinical populations (Riches et al., 2010). With the work of Slobin and Welsh (1968) and Clay (1971), SRep became an important paradigm in the 1960s (Riches et al., 2010). To repeat the sentence verbatim beyond participants' word span, participants need to use both their STM and the syntactic knowledge to "chunk" the stimulus to the long-term memory (LTM) (Slobin &Welsh, 1968; Clay, 1971). SRep tasks have been widely used for measuring language skills (Klem et al., 2015) and have been found useful in identifying language impairments (Marinis & Armon-Lotem,2015). When compared to the non-Word repetition (NWRep) tasks, sensitivity and specificity have been found greater in SRep tasks (Conti-Ramsden et al., 2001), and therefore, more challenging.

It has been suggested that SRep could be used as a clinical marker for specific language impairment (SLI; e.g., Everitt & Conti-Ramsden, 2013), and could be used for investigating syntactic development (Boyle et al., 2013). Although SRep tasks have been more often used in individuals with SLI, it should be noted that autistic individuals have similar difficulties with processing syntactically complex sentences (Montgomery & Evans, 2014). Nevertheless, due to the heterogeneity in linguistic profiles among autistic individuals (Tager-Flusberg, 2006), it is still unclear what linguistic knowledge is needed to perform on such a task (Polišenská et al., 2015).

To better understand diverse syntactic impairments in autistic children, Sukenik and Friedmann (2018) investigated types of errors in production and comprehension tasks. The results showed that although autistic children scored low overall, their types of errors were highly heterogeneous on the SRep irrelevant of the sentence complexity (simple vs embedded sentences). This is in line with Brynskov et al. (2016) who also found wide variability in performance on the SRep (CELF Preschool-2; Wiig et al., 2004) among autistic children. Notably, autistic children with language delay showed impaired performance on SRep whereas autistic children without language delay had intact performance when recalling sentences. According to some authors (e.g., Clay, 1971), it is plausible that autistic individuals who show intact SRep performance have enhanced short-term memory which allows them to recall sentences correctly without fully comprehending them. Such an explanation contradicts other authors claiming that SRep is not a 'pure' measure of short-term memory span but involves other factors such as comprehension abilities (Riches et al., 2010) and word familiarity (Polišenská et al., 2014).

As humans, we tend to almost automatically memorize information that we are familiar with, especially if that information is presented to us in a simple coherent and meaningful format (Chartrand & Bargh, 1996). Participants show greater recall for words organized into sentences, rather than randomly ordered words on SRep tasks (e.g., Jefferies et al., 2004; Polišenská et al., 2015). In a delayed SRep task, the effects of plausibility are so prominent that due to its impact, adults' recall boosted, and this effect increased as the task complexity increased (Polienská et al., 2014). Plausible information is more likely to have happened in real life, triggering semantic representations, and so is more likely to be encoded by the listener, making recall easier. However, autistic individuals have difficulties with recall when they need to make semantic associations between unrelated words, whereas controls do not (Tager-Flusberg, 1991).

Relating back to often enhanced auditory abilities in autism (Mottron et al., 2000); it is not surprising that some studies reported increased attention span among autistic participants due to the involvement of musical elements in a task (Claussen & Thaut, 1997; Schwartzberg & Silverman, 2012). Schwartzberg and Silverman (2018) examined the effects of presentation style and musical elements on working memory in autistic individuals and their controls, where controls demonstrated a significantly higher mean sequential memory recall than autistic individuals, which is in line with previous research (Williams et al., 2005; DiCicco-Bloom et al., 2006; Schwartzberg & Silverman, 2012). These results agree with the findings of other studies, in which autistic individuals demonstrate poorer STM across different conditions (e.g., digit recall versus serial recall), when compared to controls (Poirier et al., 2011).

Even though comprehension deficits (Chan et al., 2005), as well as poor STM (e.g., Schwartzberg & Silverman, 2018) are well reported in autism, only 14 behavioural studies examined SRep in autistic individuals from 2010 to 2021 (Rujas et al., 2021). Considering studies using SRep in English speaking autistic individuals only, various aims were investigated: early language milestones and later structural language (Kenworthy et al., 2012), heterogeneity in linguistic profiles (Harper-Hill et al., 2013; Riches et al., 2010; Taylor et al., 2014; Norbury et al., 2017), and improving an automatic speech recognition (ASR) system (Gale et al., 2019). Such studies demonstrated that autistic individuals who show difficulties on SRep tasks also exhibit greater autistic symptomatology and attention deficits (Harper-Hill et al., 2013), and have distinct linguistic profiles from individuals with language impairments (Taylor et al., 2014).

Previous studies have primarily focused on using standardized tests for measuring participants' recall, which may not grasp the entire linguistic profile of autistic individuals (Wittke et al., 2017), whereas previous studies using novel experimental tasks have not employed different conditions that may have an impact on participants' recall (e.g., spoken vs sung format). Such studies have mainly tested children and/or adolescents. Taking language and communication impairments across autistic lifespan (Ha et al., 2015) into account, exploring SRep accuracy in autistic adults using sentences that resemble everyday situations warrants further investigation.

Current study

Most of the previous research has focused on using either non-word repetition (Coady & Evans, 2008), a single word repetition or on using standardized sentence repetition tasks. Hence, there is a lack of studies looking into complex syntactic sentence structures, as well as the ones controlling for other important variables, such as verbal STM. This study aimed to extend previous work done by Liu et al. (2015) where News-like sentences (Nazzi, Bertoncini, & Mehler, 1998) were used on Mandarin listeners. It was found that individuals with congenital amusia experienced speech comprehension difficulties in everyday listening situations when compared to controls. Similarly, autistic individuals often show impaired speech comprehension (e.g., Key & D'Ambrose Slaboch, 2021) which additionally becomes more demanding if background noise is added (Stevenson et al., 2017).

3.2 Aims

To our knowledge, no previous study examined SRep in autistic adults, while considering several types of *Content*, the presence of the multi-talker babble *Noise* (Valentini-Botinhao, 2017), and the *Form* of the utterances (spoken vs sung). We also wanted to investigate whether participants' recall would be more accurate in the condition where the utterances were spoken or sung. Since correlations between measures of non-verbal cognitive abilities and language abilities are well reported (Kjelgaard & Tager-Flusberg, 2001), we controlled for the following measures: abstract reasoning (Raven's Matrices; Raven et al., 1989), receptive vocabulary (The Receptive One-Word Picture Vocabulary Test-4; ROWPVT-4, Martin & Brownell, 2010/2011), and Psychology Experiment Building Language (PEBL) digit span test (verbal STM) (Mueller, 2014; Mueller & Piper, 2014). Finally, Montreal Battery of Evaluation of Amusia (MBEA) was used to pre-screen any participants who may be 'tone-deaf' (Peretz et al., 2003). Thus, only participants who scored in the normal range on their general musical abilities, were included in the study.

The following hypotheses were expected:

1. Overall, controls will have a higher accuracy on the SRep task, irrelevant of experimental conditions, when compared to autistic individuals.

2. Participants' SRep accuracy will be higher while repeating story-like, followed by news-like sentences, when compared to nonsensical sentences.

3. Participants' SRep accuracy will be lower in the noise condition, when compared to the no noise condition. We expect autistic individuals to have a bigger difference in their SRep accuracy between the noise and no noise conditions, when compared to controls.

4. Controls' SRep accuracy will be higher in the spoken condition, when compared to sung condition. On the contrary, we expected autistic individuals to have higher SRep accuracy in the sung condition, compared to spoken condition.

3.3 Method: Experiment 2.1

Participants

Participants were recruited through the SONA system and were all Psychology students at the University of Reading. Upon completion, participants were assigned credits for their participation. Two autistic participants were recruited through the existing lab database and were reimbursed £7.50 per hour of their time. All participants were adults and British English native speakers. Participants were 33 controls (eight males) between 19 and 46 years of age (*M* = 24.12, *SD* = 6.09) and 5 autistic individuals (two males) between 21 and 30 years of age (*M* = 23.40, *SD* = 3.78). Participants in the control group were healthy individuals with no hearing nor speech problems, whereas all autistic participants received a formal diagnosis of autism or Asperger syndrome by a qualified clinician using DSM-IV or DSM-5 criteria (APA, 2013).

Materials

Background measures

All participants completed: The Receptive One-Word Picture Vocabulary Test (ROWPVT-4; Martin & Brownell, 2011), Raven's Standard Progressive Matrices Test (Raven et al., 1989), as part of the pre-screening process. The same pre-screening criteria applied as in Study 1: a standard score of 70 on the receptive vocabulary test, and a score of at least equal to or larger than 5th percentile on Raven's test to take part in the study. Participants who failed to reach either of the screening requirements were excluded from further testing. Other background measures included verbal short-term memory, autistic traits questionnaire and MBEA. The forward digit span task was used to assess participants' verbal short-term memory (Mueller, 2014), and autistic traits were measured using the AQ (Baron-Cohen et al., 2001). The MBEA task was administered using Praat (Boersma, 2001), and participants completed six subtests: Scale, Different Contour, Same Contour, Rhythmic, Metric task, and Incidental Memory test. All participants had normal hearing in both ears, with pure-tone air conduction thresholds of 25 dB HL or better at frequencies of 0.5, 1, 2, and 4 kHz.

Written informed consent was obtained from all participants, and the study was approved by the University Research Ethics Committee (UREC 16/37, end date: 30 November 2022) at the University of Reading (Great Britain).

Experimental task: Sentence Repetition Task (SRep)

The stimuli were comprised of 20 *news-like* sentences (e.g., “The princess is a well-known international figure.”) adapted from Nazzi et al. (1998), 20 *story-like* sentences (e.g., One day an old woman ran up and down in a spotty cloak.”) adapted from various stories (e.g., The tale of Mrs Tittlemouse), and 20 nonsensical sentences (e.g., “The metal enables the heat to eat.”). Each sentence was comprised of 10-21 syllables. Half of the sentences contained Multitalker babble noise, and the other half did not contain any background noise. Babble noise contained 56 speaker dataset and was adopted as a .wav file from the University of Edinburgh online repository (Valentini-Botinhao, 2017). As some parts of the data set contained one speaker only, FL and CZ manually edited the noise using Praat (Boersma, 2001), so that it always contains Multitalker noise. GA, who sang the sentences neutrally, created the sung version of the stimuli. The aim was to create sung sentences that resemble *speech-in-song,* whilst matching acoustic features between conditions (spoken vs sung) as closely as possible (see Table 3.2 for details). Each sentence had four versions: sung with/without babble noise and spoken with/without babble noise. Using a Latin square design, each sentence was played once to a participant. Participants went through six practice trials before starting the main trials, so that they could ask any questions they might have had. There were 60 experimental trials in total.

Procedure

The procedure of collecting background measures is the same as described in Procedure section for Study 1. For the main experimental task, participants were tested in a soundproof booth, where they were comfortably seated in front of a computer and heard the experimental task through a pair of a headset with a microphone. Prior to the main trials, participants were given practice trials and were asked if they had any questions. Participants were asked to immediately repeat back the sentence they have previously heard by speaking clearly into the microphone. Participants were instructed to try to recall the material to their best ability while ignoring the background noise. Participants were also instructed not to sing but to repeat the sentence by speaking, even in the sung condition. The task took 10-20 minutes to complete. Upon completion, the experimenter manually saved participants' recording in Praat as a .wav file (Boersma, 2001).

Scoring

Participants received one point for each word recalled correctly or no points for either wrongly recalled words or 'no response' answers. As in Polisenska Chiat, and Roy (2015), we used the method of 'span' which establishes the maximum number of words that participants are able to repeat correctly per sentence. Participants' self-adjusted answers were accepted, and no points were deducted for minor mistakes (e.g., 'thousand' instead of 'thousands'). Scores were then summarized for each condition (e.g., *News-like, speech, no noise*), divided by the total number of words per sentence, and then transformed to rationalized arcsine transform (RAU) scores using a scoring template in Excel. RAU scores are used to transform data obtained from speech intelligibility tests to make them suitable for parametric statistical analyses (e.g., Sherbecoe & Studebaker, 2004, Studebaker et al., 1995). The total number of words per each condition can be found in Table 3.1, and acoustic features extracted from spoken and sung targets are presented in Table 3.2. The details of the experimental sentences can be found in Appendix A.

Table 3.1

Experimental conditions and the average number of words per sentence

Experimental condition	Average number of words per sentence
News, speech, no noise	9.8
News, song, babble noise	10.2
News, song, no noise	9
News, speech, babble noise	9.2
Nonsensical, speech, no noise	9.8
Nonsensical, song, babble noise	9.8
Nonsensical, song, no noise	9
Nonsensical, speech, babble noise	9.6
Story, speech, no noise	11.2
Story, song, babble noise	11.4
Story, song, no noise	11.6
Story, speech, babble noise	10.2

Table 3.2

A summary of acoustic features extracted from spoken and sung targets

Target	*M* F_0 (Hz)	Min F_0 (Hz)	Max F_0 (Hz)	*M* duration (sec)	*M* Tempo (bpm)
Speech	242.68	150.14	316.82	2.61	NA
Music	301.50	184.18	385.73	5.53	113

3.4 Results: Experiment 2.1

Descriptive data

As in previous empirical chapters, participants' scores on Raven's matrices are reported as raw scores (out of 60), whereas the ROWPVT-4 scores are reported as standardized scores. MBEA scores are reported as percentages of correct responses on participants' global scores. The groups did not differ on any of the background measures, except for the AQ scores where autistic individuals had significantly higher autistic traits, when compared to controls, t (36) = -4.46, p< .001. The descriptive data can be found in Table 3.3.

Table 3.3

Background measures' descriptive data

	Controls		Autistic group			
Measure	*M*	*SD*	*M*	*SD*	*t*	*p*
Raven's matrices	51.94	4.36	53.4	3.78	- 0.68	.5
ROWPVT-4	104.61	12.53	103.2	18.9	0.22	.83
The AQ	16.36	8.04	33.8	8.98	-4.46	< .001
Global MBEA	84.7	6.78	90	3.16	-1.53	.14
Digit span	7.27	1.35	7.25	0.96	0.03	.97

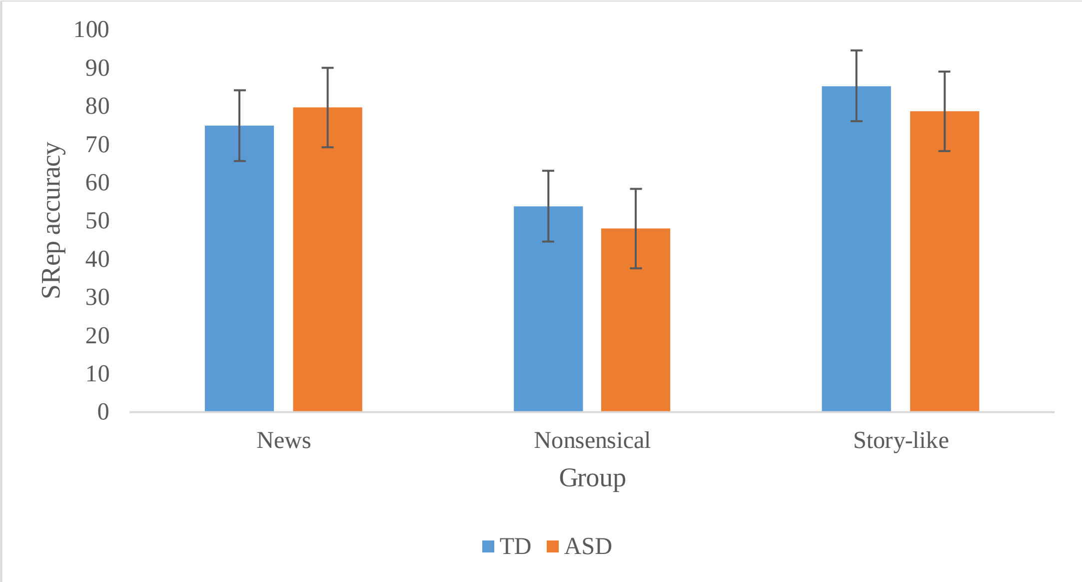
Analysis of the main experimental task: SRep

A mixed factor ANOVA with one-between subject factor (Group), and three within-subject factors (Content, Form, Noise) was conducted using SPSS software. The Group consisted of 2 levels: controls and autistic individuals, whereas the Content was comprised of 3 levels: news-like, story-like, and nonsensical sentences. The Form was comprised of two levels: spoken and sung sentences, and finally, the Noise was comprised of two levels: no noise, and Multitalker babble noise. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, ($\chi^2(2) = 1.84$, $p = .40$) and each participants' data included 12 Mean RAU scores in total, across all conditions (e.g., Mean RAU score for the following conditions: news-like, speech, no noise).

Data obtained from 33 controls and 5 autistic individuals showed that there was no statistically significant difference between the groups on the SRep task performance (F (1,36) = 0.28, $p = .60$). However, there was a statistically significant effect of Content on participants' recall (F (2,35) = 184.68, $p < .001$). Paired samples t-tests have confirmed that participants had a significantly more accurate recall for *story-like* sentences (M = 84.49, SD = 17.58) than for *news-like* sentences (M = 75.57, SD = 20.19; t (37) = 6.26, $p < .001$). In addition, participants have performed significantly better when recalling *news-like* sentences, when compared to *nonsensical* sentences (M = 53.11, SD = 14.12; t (37) = 17.35, $p < .001$). Finally, participants had significantly more accurate recall for *story-like* sentences than for *nonsensical* sentences (t (37) = 29.91, $p < .001$) (see Fig 3.1).

Figure 3.1

SRep accuracy measured by mean RAU scores across different types of the content



There was also a statistically significant effect of Noise (*F* (1,36) = 303.06, *p*< .001), where participants had a better recall in the no noise condition (*M* = 86.28, *SD* = 17.26), when compared to the Multitalker babble noise condition (*M* = 53.92, *SD* = 13.56).

In addition, both Content*Group (*F* (2,35) = 6.67, *p* = .002) and Noise*Group (*F* (1,36) = 4.63, *p* = .04) interactions were statistically significant. Finally, both the effect of Form, and the Form*Group interaction were non-significant, *p*> .05. The data for each mean RAU score across all conditions can be found in Table 3.4.

Table 3.4

Participants' mean RAU scores across all experimental conditions

	Controls		Autistic group	
Conditions	*M*	*SD*	*M*	*SD*
News, speech, no noise	89.37	15.68	90.82	19.63
News, song, babble noise	64.12	15.75	56.99	14.04
News, song, no noise	93.74	16.13	108.32	7.42
News, speech, babble noise	52.56	11.15	62.60	27.90
Nonsensical, speech, no noise	66.54	14.24	63.49	15.03
Nonsensical, song, babble noise	45.71	13.62	34.89	17.30
Nonsensical, song, no noise	64.40	12.49	62.07	22.88
Nonsensical, speech, babble noise	38.89	11.16	31.63	13.26

Story, speech, no noise	101.77	11.50	103.97	19.61
Story, song, babble noise	73.56	17.47	54.76	38.30
Story, song, no noise	97.66	10.29	93.21	7.51
Story, speech, babble noise	68.49	12.54	62.85	19.75

Content*Group interaction

In order to understand the Content*Group interaction results better, three independent t-tests were used to determine the difference between the groups for each type (*Content*) of the sentence (e.g., Mean RAU score for *News-like* sentences minus Mean RAU score for *Nonsensical* sentences).

Levene's tests of equality of variances have been non-significant for each independent t-test reported below ($p > .05$).

News-like and nonsensical sentences

It was found that groups significantly differed in their recall on *news-like* sentences, when compared to *nonsensical* sentences, t (36) = -3.07, p = .004. In other words, it seems that the Content*Group interaction was at least partially driven by a larger difference in RAU scores between *News-like* and *Nonsensical* sentences among autistic individuals (*M* = 31.66, *SD* = 9.25), when compared to controls (*M* = 21.06, *SD* = 6.90).

Story-like and news-like sentences

It was found that the Group difference in RAU scores between *story-like* sentences, and *news-like* sentences was found to be statistically significant as well, t (36) = 2.98, p = .005. That is to say the difference in RAU scores was larger between *Story-like* and *News-like* sentences among controls (*M* = 10.42, *SD* = 8.15), when compared to the autistic group (*M* = -0.99, *SD* = 6.36). This is due to the fact that, on average, controls have recalled *story-like* sentences more accurately than *news-like* sentences, whereas this pattern was reversed in autistic individuals (see Figure 3.1).

Story-like and nonsensical sentences

There was no statistically significant difference between the groups' performance when comparing the difference in RAU scores between *Story-like* and *Nonsensical* sentence recall, t (36)= 0.26, p = .79, meaning that the difference between recalling story-like and nonsensical sentences did not differ between controls (*M* = 31.49, *SD* = 6.65) and autistic individuals (*M* = 30.68, *SD* = 5.70).

Noise*Group interaction

Another independent t-test was performed in order to explain the Noise*Group interaction. It was found that there was a statistically significant difference between the groups on their recall between No noise and Multitalker noise conditions (t (36) = 2.15, p = .04). Although paired t-tests have shown that both controls (t (32) = 22.52, p< .001), and autistic individuals (t (4) = 7.37, p = .002) had a more accurate sentence recall in the No noise condition when compared to the Multitalker noise condition, the interaction was driven by the fact that the autistic group had a larger difference in their sentence recall between two conditions (M = 36.36, SD = 11.03), when compared to the controls (M = 28.36, SD = 7.23). In other words, it could be said that autistic individuals' performance was more negatively influenced by the Multitalker noise condition, when compared to controls' performance (Figure 3.2).

Figure 3.2

SRep accuracy measured by mean RAU scores in quiet and noisy conditions

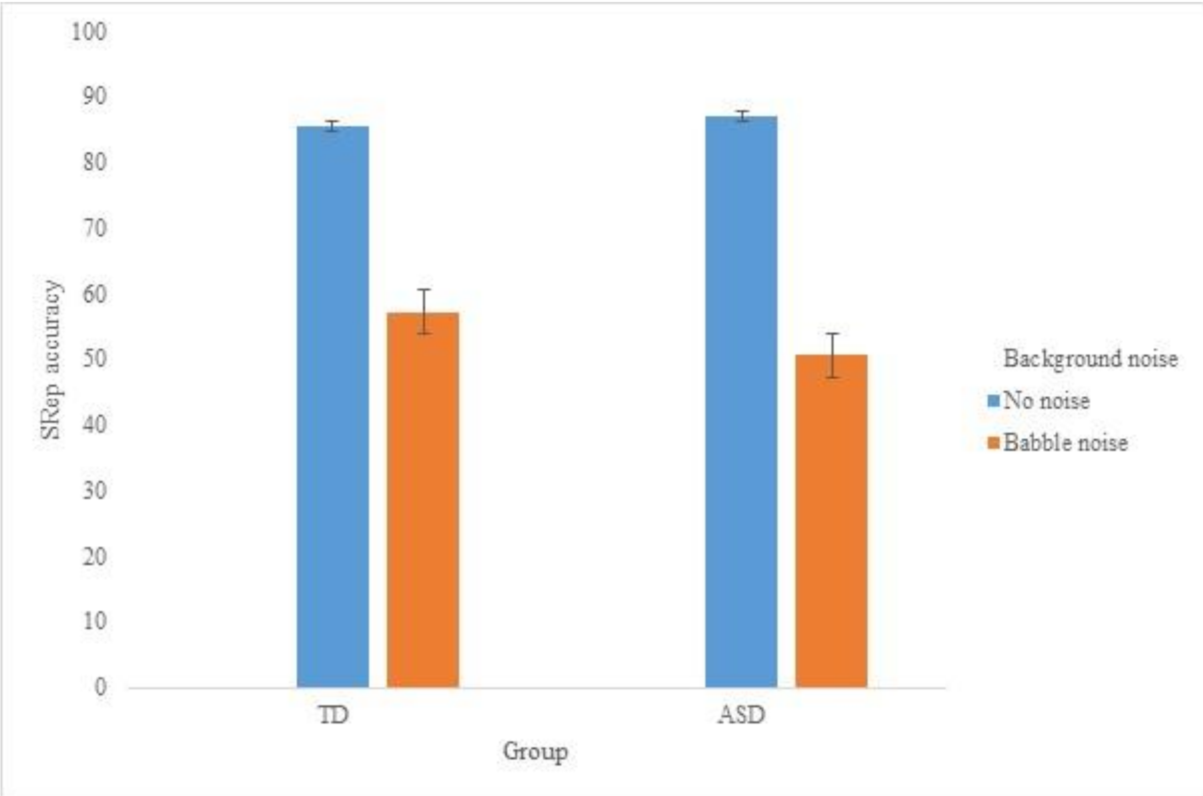
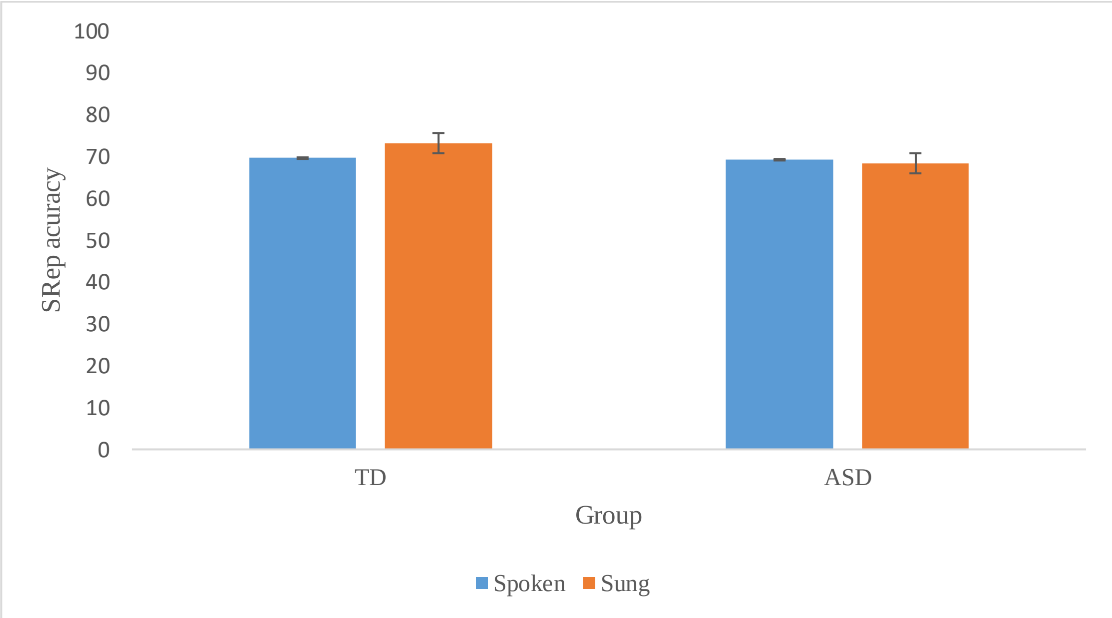


Figure 3.3

SRep accuracy measured by mean RAU scores across spoken and sung conditions



3.5 Discussion: Experiment 2.1

The present study explored participants' verbatim immediate sentence recall in a novel task while considering the effects of the *Content*, the *Form*, and the Multitalker background *Noise* by comparing autistic individuals' performance to the control group. As predicted, participants' SRep accuracy was higher when recalling story-like, and news-like sentences, when compared to nonsensical sentences. In addition, statistically significant interactions were found. Namely this related to the interaction between the Group and the Content, where participants' recall was more accurate for story-like and news-like sentences when compared to nonsensical sentences. Another interaction was found between the Group and the Noise condition, where autistic participants had more difficulties recalling the material in noisy condition, when compared to controls. Although we did not find a group difference on overall SRep accuracy, we found a main effect of the Noise, as predicted. Finally, against expectations, we did not find any difference on participants' SRep accuracy when comparing recall performance between spoken and sung sentences.

Participants had higher accuracy while recalling story-like, and news-like sentences, when compared to nonsensical sentences, and this is consistent with previous findings that participants are less able to recall ambiguous sentences when compared to unambiguous sentences (Holmes et al., 1977; Aurnhammer-Frith, 1969). In addition, this is in line with previous research confirming that participants tend to have difficulties recalling nonsense words when compared to meaningful words and sentences (Polišenská, Chiat, & Roy, 2015).

It is plausible that we did not find any group difference on the SRep performance because our groups were matched on some important background measures. It is well reported that the receptive vocabulary is related to the SRep performance, as well as the verbal STM. For instance, in a study done by Gathercole and Baddeley (1990), it was proposed that previous vocabulary knowledge enhances verbal short-term memory, and therefore repetition accuracy. Our sample size was limited due to COVID-19 restrictions, so perhaps due to this limitation, we could not capture the true group difference where controls would outperform autistic individuals. It has been discussed whether the SRep performance depends solely on the working memory capacity or not. It was, indeed, found that SRep measures memory capacity in cases where sentences are very short and participants can simply rely on passive copying mechanisms (Marinis & Armon-Lotem, 2015). To address limitations of previous studies, we have matched our participants on a group level on the following measures: receptive vocabulary, non-verbal abstract reasoning, global musical abilities, and verbal short-term memory. Previous research is in agreement that SRep accuracy depends on age, memory capacity and language abilities. Since our adult participants were matched on a group level on receptive vocabulary and verbal STM, while we tested their SRep accuracy on different types of sentences in our study, we could say that it is unlikely that our SRep purely measured participants' STM.

We expected to find a group difference on the SRep task where controls would outperform autistic individuals in the Multitalker noise condition. Although this was not the case in the current study, looking more closely into the Group and Noise interaction, we have found that autistic individuals' performance had a larger difference on the SRep accuracy when comparing the noisy condition, to the no noise condition, whereas controls performed more similarly between the two conditions. This is consistent with the previous literature investigating the 'cocktail-party' phenomenon where autistic individuals tend to have difficulties understanding speech-in-noise when compared to the controls (Alcántara et al, 2004). This auditory filtering impairment present in autistic individuals happens due to their sensory sensitivity issues where they find it difficult to filter the speech from the background noise (Dahary et al., 2018).

As for the Form factor, where we expected controls to have better SRep accuracy while recalling spoken sentences, and better SRep accuracy in autistic individuals while recalling sung sentences, no differences emerged. There is still an ongoing debate as to whether music facilitates sentence recall, but in our study, we expected a better recall for spoken sentences in controls. This is because it was hypothesised that sung sentences might be more complex material to recall, and therefore more difficult and less accurately recalled than spoken sentences. It could be that our sentences were quite simple (e.g., The man was jailed for contempt of the court) and sounded similar in both spoken and sung versions, so participants did not differ in their performance between the two conditions. The results contradict previous studies claiming that music enhances text recall (Wallace, 1994; Salcedo, 2010). However, it should be noted that this effect disappears when possible, confounds are controlled for (e.g., long-term memory, and familiarity) (Racette & Peretz, 2007), which is in line with the current study. In addition, the student who recorded our stimuli did not follow a strict standardized musical protocol while singing the utterances.

Following COVID-19 restrictions in March 2020, the data collection had to be paused so the current findings should be considered as preliminary only. We did not have a representative sample as we only tested five autistic individuals, and this might have significantly reduced the power of study's results (e.g., Button et al., 2013; Schweizer & Furley, 2016). For instance, when recalling News-like sentences, although not statistically significant, we found that autistic individuals scored better than our controls did.

Due to the heterogeneity in linguistic profiles among autistic individuals (Lombardo et al., 2019), we should have tested more participants in this group. Due to COVID-19 disruptions, we created an online version of the experiment, and included some background measures that closely relate to the measures used in our lab setting. The details can be found in Experiment 2.

3.6 Method: Experiment 2.2

Participants

Participants were recruited through Prolific and took part in the study online using Gorilla. Upon completion, participants were reimbursed £7.5 per hour for their participation. The data collection started in June 2021 and took about a week to complete.

All participants were adults and British English native speakers. Participants were 15 controls (all females) between 19 and 46 years of age (*M* = 32.86 *SD* = 10.53) and 19 autistic individuals (seven males, one 'Prefer not to say', and one 'Other') between 18 and 54 years of age (*M* = 28.78, *SD* = 9.56). Participants in the control group were healthy individuals with no reported speech problems, whereas all autistic participants reported that they have autism diagnosis on their profiles on Prolific. In addition, as part of the information sheet, participants were asked whether they had a clinical diagnosis of any of the following: Autism spectrum disorder (ASD), Dyslexia, Attention-deficit disorder (ADD)/Attention deficit hyperactivity disorder (ADHD), Depression, Anxiety, another mental health condition, a chronic physical health condition, or none of the above. The purpose of the screening question was to collect data for other studies as part of the CAASD lab, which is why it included other conditions other than autism. It was not possible to identify if the participants in the autism group indeed had a clinical diagnosis of autism or not. For those reasons, we have also included the AQ to measure the degree of participants' autistic traits (Baron-Cohen et al., 2001).

Materials

Background measures

All participants completed the following background measures: the AQ questionnaire (Baron-Cohen, 2001), a forward digit span task, MBEA (Peretz, Champod, & Hyde, 2003), and DearyLiewald Task (Deary et al., 2010). The AQ questionnaire followed the same format as for in-lab testing. The forward digit span task was created using random numbers and participants were presented with two trials of each digit length starting at two digits (e.g., 43). The maximum length presented was nine digits, so the highest number of trials was 18. The MBEA task followed the same format as for in-lab testing, and the Deary-Liewald Task was comprised of Simple Reaction Time (RT), and a Choice RT.

All tasks began with their description, followed by the instructions and practice trials, apart from the AQ questionnaire.

Experimental task: SRep

The stimuli were identical to those used in a lab setting from Experiment 1. However, due to the nature of online testing, we have included a catch trial where participants were asked to repeat back '*Happy birthday'* either in a spoken or a sung format.

Procedure

Since the data was collected online, participants were asked to take part in the study in a silent place where they could be comfortably seated in front of a computer. Participants were also told that they would need a headset with a microphone. Prior to the main trials, participants were given practice trials for all tasks, apart from the AQ.

For the forward digit span task, participants were instructed on the screen that they would be presented with a sequence of numbers and that, once the numbers disappear from the screen, they will be asked to write them down in the exact order they were presented. The task took about five minutes to complete.

The MBEA task was comprised of six different subtests, and to make sure that participants were paying attention to the task, we have included catch trials for the following subtests: Scale, Contour, Interval and Rhythm. Each subtest took between 8-10 minutes to complete.

The Deary-Liewald Task (Deary, Liewald & Nissan, 2010) was comprised of 2 subtests: simple RT and choice RT. In the simple RT task, participants were told to press the Spacebar as soon as an 'X' appeared in the box. In the choice RT task, there were four boxes on the screen. Participants were given the following instructions: If the X appears in the first box, press the 'z' key; if the X appears in the second box, press the 'x' key, if the X appears in the third box, press the ',' key, and if the X appears in the last box, press the '.' Key.

The 'wait time' for an X to appear ranged from 150ms to 1500ms for the simple RT, and ranged from 200ms to 1500ms for the Choice RT. There were 20 trials in total for the simple RT, and 40 trials in total for the Choice RT task. The task took about five minutes to complete.

During the SRep task, participants were asked to repeat back the sentence they have previously heard by speaking clearly into the microphone. Participants were instructed to try to recall the material to their best ability while ignoring the background noise. Participants were also instructed not to sing but to repeat the sentence by speaking, even in the sung condition. A 'randomizer' node on Gorilla was used to make sure that participants were randomly assigned one of four different experimental lists. The task took between 10 to 15 minutes to complete all 60 trials. Upon completion of all tasks, participants were presented with a Debrief information sheet on the screen and have received a payment for their participation. Since the study was conducted online, participants could take the time they needed before proceeding to the next task. On average, it took participants 30-40 minutes to complete all tasks.

3.7 Results: Experiment 2.2

Descriptive data

Due to participants' attrition, one participant's data was missing for the Simple RT task, and seven participants' data were missing for the Choice RT task. These individuals were removed from the analysis of independent t-tests. The groups did not differ on any of the background measures, expect for the AQ scores where autistic individuals had significantly higher autistic traits (M = 35.21, SD = 7.66), when compared to controls (M = 20.53, SD = 9.05), t (36) = -4.46, p< .001). The background measures' descriptive data can be found in Table 3.5, and experimental descriptive data is presented in Table 3.6.

Table 3.5

Background measures' descriptive data

Measure	Group	*N*	*M*	*SD*	*t*	*p*
Age	Autistic	19	28.78	9.56	-1.15	0.26
	Control	15	32.86	10.53		
The AQ	Autistic	19	35.21	7.66	-4.46	< .001
	Control	15	20.53	9.05		
MBEA	Autistic	19	78.05	13.07	-0.50	.62
	Control	15	80.07	9.29		
Simple RT	Autistic	18	96.38	6.37	-1.45	.16
	Control	15	99.00	2.07		
Choice RT	Autistic	17	90.00	16.84	1.29	.21
	Control	10	93.75	4.45		

Table 3.6

Participants' mean RAU scores across all experimental conditions

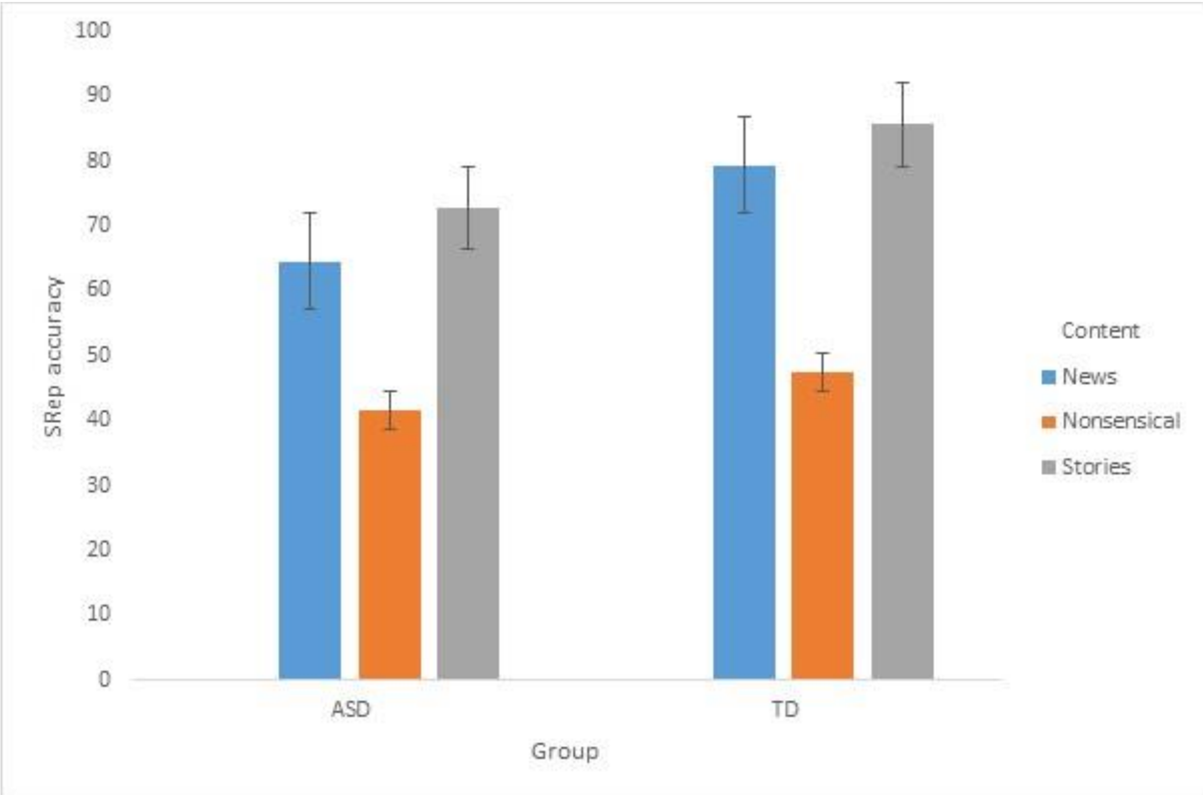
Conditions	Controls		Autistic group	
	M	*SD*	*M*	*SD*
News, song, babble noise	65.34	21.96	47.05	26.67
News, song, no noise	96.56	18.00	86.52	19.98
News, speech, babble noise	54.00	17.67	38.25	21.77
News, speech, no noise	101.38	15.23	86.06	16.49
Nonsensical, song, babble noise	33.48	16.94	30.11	22.85
Nonsensical, song, no noise	58.88	17.80	56.34	20.27
Nonsensical, speech, babble noise	32.68	14.72	22.01	21.29
Nonsensical, speech, no noise	64.70	12.62	57.64	26.19
Story, song, babble noise	67.01	20.33	49.90	26.34
Story, song, no noise	104.48	12.56	94.40	14.22
Story, speech, babble noise	69.20	12.41	52.36	18.25
Story, speech, no noise	101.73	13.14	94.55	14.83

Analysis of variance (ANOVA)

As in Experiment 1, a mixed effects ANOVA with one-between subject factor (Group), and three within-subject factors (Content, Form, Noise) was conducted using SPSS software. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, ($\chi^2(2) = 4.43$, $p = .11$), so the criteria for parametric testing was satisfied. Data obtained from 15 controls and 19 autistic individuals showed that there was a statistically significant difference between the groups on the SRep task performance, $F(1,32) = 6.08$, $p = .019$, $\eta_p^2 = .160$. This reflects that controls had a more accurate SRep recall (*M* = 70.78, *SD* = 3.39), when compared to the autistic individuals (*M* = 59.6, *SD* = 3.01). In addition, there was a statistically significant effect of the Content on participants' recall, $F(2,32) = 154.73$, $p < .01$, $\eta_p^2 = .327$ (see Figure 3.4). To understand the main effect of the Content better, paired t-tests have been performed to see how participants' recall accuracy differed between story-like, news-like, and nonsensical sentences.

Figure 3.4

SRep accuracy measured by mean RAU scores across different types of the content



Paired samples t-tests have confirmed that participants had a significantly more accurate recall for story-like sentences (*M* = 78.45, *SD* = 13.75), when compared to the news-like sentences (*M* = 71.02, *SD* = 16.56, *t* (33) = 4.08, *p*< .001. In addition, participants have performed significantly better while recalling story-like sentences, when compared to the nonsensical sentences (*M* = 44.13, *SD* = 16.89, *t* (33) = 17.49, *p*< .001. Finally, participants recalled news-like sentences more accurately, when compared to nonsensical sentences as well, *t* (33) = 10.76, *p*< .001.

There was also a statistically significant effect of Noise, *F* (1,32) = 315.51, *p*< .001, η_p^2 = .908, where participants had a more accurate recall in the No noise condition (*M* = 83.09, *SD* = 11.85), when compared to the Noise condition (*M* = 45.97, *SD* =18.19).

Both interactions Content*Group (F (2,31) =2.53, p = .09), and Noise*Group (F (1,32) =1.44, p = .24) were found to be not statistically significant. Finally, both the effect of Form (F (1,32) = .99, p = .32) and the Form by Group (F (1,32) = 0.54, p = .47) interactions were non-significant as well.

Figure 3.5

SRep accuracy measured by mean RAU scores split by the noise condition

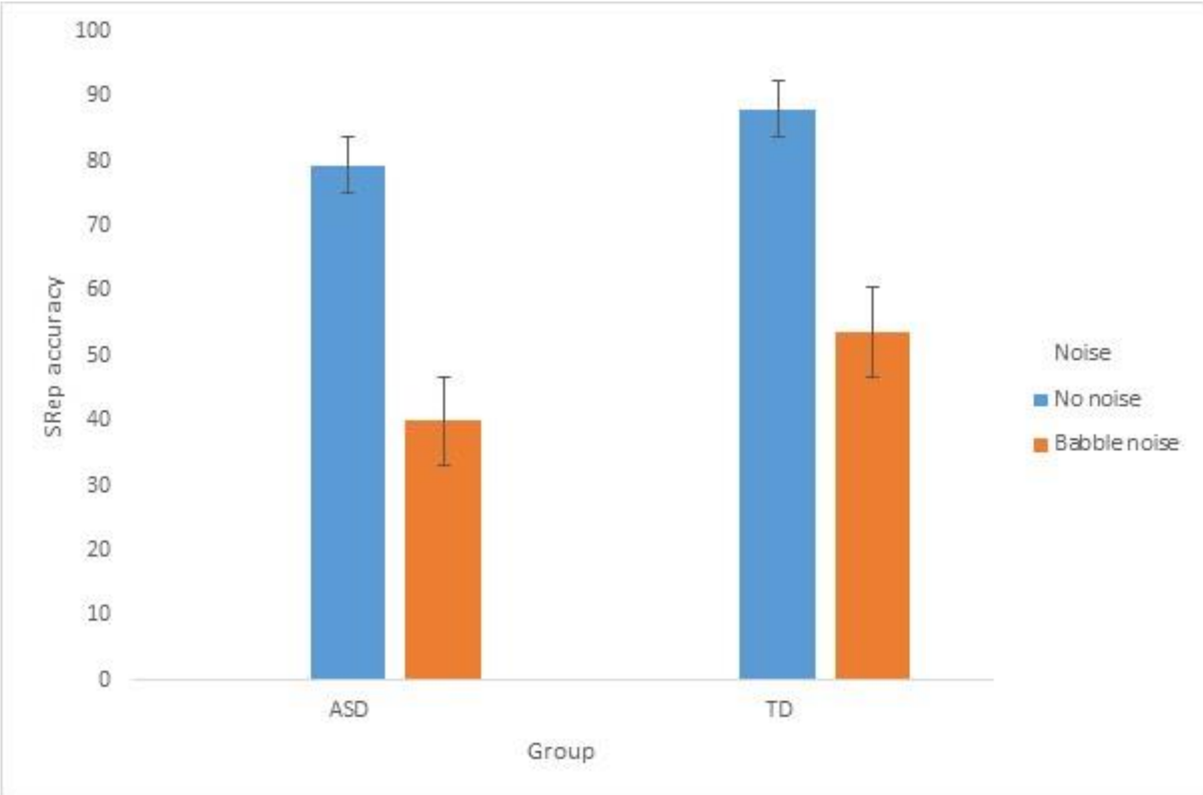
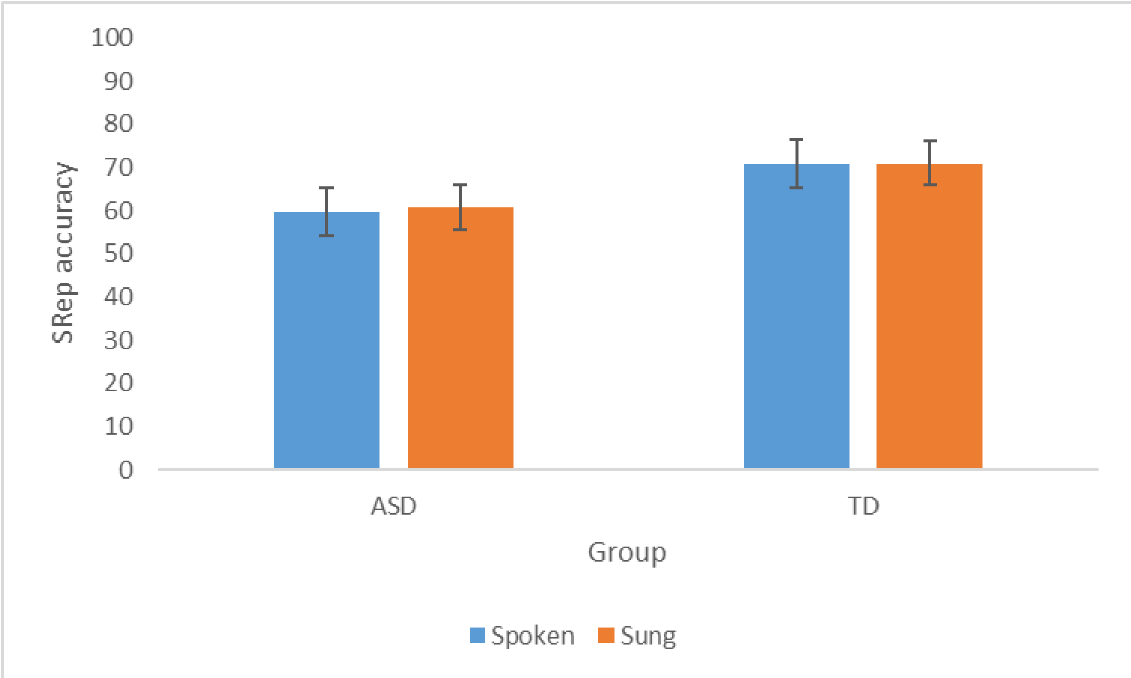


Figure 3.6

SRep accuracy measured by mean RAU scores split by the form condition



3.8 Discussion: Experiment 2.2

The present study explored participants' verbatim sentence recall using the same task as in Experiment 1 using an online platform Gorilla. Since the data collection for Experiment 1 was incomplete, we used Experiment 2 to test the same hypotheses while testing more participants in the autism group. Due to participants' disengagement in online studies (e.g., Zhou & Fishbach, 2016), we have incorporated catch trials ('Happy birthday' song/speech). In addition, we have also tested our participants on general musical abilities, and verbal short-term memory, as to avoid any confounding variables affecting the results (e.g., 'tone-deaf' participants). As predicted, we have found a group difference on the SRep task performance, where the control group had a higher recall accuracy when compared to the autism group. Overall, participants had a significantly more accurate recall for story-like sentences, followed by news-like sentences, and the lowest recall accuracy for nonsensical sentences. In addition, participants had a significantly higher SRep recall in the No noise condition, compared to the Noise condition but this did not differ between the groups. Finally, contrary to expectations, the Form (spoken vs sung) did not affect participants' SRep accuracy.

The group difference on the SRep task, where controls had a better sentence recall, when compared to the autistic individuals, is in line with previous studies reporting poorer sentence repetition in the autism group (e.g., Harper-Hill, Copland & Arnott, 2013, Taylor et al., 2014). As in Experiment 1, the highest accuracy was found for story-like sentences, followed by news-like sentences, and the lowest accuracy for nonsensical sentences, which is consistent with previous research claiming that plausible sentences activate stronger semantic representations, facilitating recall (Polišenská et al., 2014), which is not the case for the nonsensical sentences. Story-like sentences were better recalled when compared to news-like sentences, which is in line with previous research suggesting better recall for narrative texts than expository texts (Mar et al., 2021).

Interestingly, both groups were equally affected by the noise condition. We expected autistic individuals to have more difficulties with recalling the material in the noisy condition compared to controls due to their hyper-reactivity to sounds (Gomot et al., 2008) but this was not the case in the current study. It is difficult to explain this result, but it might be related to taking part in the study from home, where participants' environment differs from the lab setting (soundproof booth). It is also plausible that the multi-talker noise we used in the study differs from the noise in real life as there were no echoes nor any other contextual cues, making recall less complex (Alcántara et al., 2004).

Contrary to what was expected, autistic individuals did not show greater recall for sung sentences compared to spoken sentences. This contradicts studies reporting greater engagement and attention during song stimuli presentation, compared to speech stimuli presentation (Lai et al., 2012; Sharda et al., 2015). Perhaps the subtle differences in stimuli across different studies caused the null results in the current study. It is also plausible that sung sentences acted as a distractor, which is in line with research reporting higher recall for spoken information compared to sung information (Wallace, 1994)

3.9 General discussion and potential limitations

There are also some differences in interactions between Experiments 1 and 2 that need to be discussed. Both interactions Content by Group and Noise by Group were found to be statistically significant in Experiment 1, whereas this was not the case in Experiment 2. In Experiment 1, controls recalled story-like sentences more accurately than news-like sentences, whereas this pattern was reversed in autistic individuals. In addition, autistic individuals had a larger difference in their recall between news-like and nonsensical sentences than controls did. Such results support previous research suggesting that typically developing individuals recall narrative texts better than expository ones (Mar et al., 2021), whereas autistic individuals may have found news-like sentences easier to recall due to their simpler structure (Gersten et al., 2001). Finally, in Experiment 1, autistic individuals' recall accuracy was more negatively affected by the noise compared to controls. This is in line with studies reporting difficulties with filtering speech in noise in autism (Alcántara et al., 2004), and greater intolerance to competing sounds compared to typically developing individuals (Sturrock et al., 2022).

There are several limitations of the study that need to be discussed. Firstly, we could not confirm the autism diagnosis for our autistic participants. When doing face-to-face data collection, participants were asked to confirm the diagnosis by providing a clinician's report. This was not possible as the data was collected online. Secondly, in our control group, we have only collected data from females. Lastly, it is advised to have at least double the number of participants when collecting data online, when compared to the lab setting to make sure that participants understand the tasks and take breaks if needed (Haffey et al., 2020).

For sample size (N = 35) in online Study 2 (mixed ANOVA), and a fixed alpha level at.05, post-hoc power calculations revealed that small (f2 = 0.02), medium (f2 = 0.15), and large (f2 = 0.35) group differences were detectable with a with power estimates of 0.06, 0.46, and 0.99, respectively. That means that the current study had adequate power to detect large group differences but inadequate power to detect medium or small group differences. In the future, it would be good to implement the same study with a larger sample size.

4 Study 3: Is autism associated with differences in melodic and linguistic expectancy?

4.1 Introduction

Communication deficits are one of the core symptoms of autism (APA, 2013). Nonetheless, as described in Study 2, linguistic profiles in autistic individuals are highly variable (Tager-Flusberg, 2004). Both pragmatic (e.g., understanding irony or metaphors; Dennis et al., 2001, Happé, 1993), and structural language (e.g.., semantics and coherence; Brook & Bowler, 1992) deficits significantly affect everyday communication (Baird & Norbury, 2016, Baixauli-Fortea et al., 2019). More recent research suggested that the inability to understand others may be due to atypical functioning of socially specific prediction errors (e.g., Sally-Anne task; Wimmer & Perner, 1983) in autism (Lawson et al., 2014; Van de Cruys et al., 2014). The inability to use additional communication cues, coupled with words that are not highly predictable (Van Petten & Luka, 2012), make it more demanding for autistic individuals to process linguistic information in context (e.g., 'In her eye/dress there was a big tear'; Happé, 1997).

Autistic individuals seem to have difficulties using contextual information when making inferences (Jolliffe & Baron-Cohen, 2000) and when predicting upcoming words (Battaglia, 2012; Catarino et al., 2011; see Barzy et al., 2020 for contradictory results) due to reduced ability to semantically integrate information (Pijnacker et al., 2010). Neuroimaging studies consistently report higher brain activation for semantically anomalous words in a sentence ("He spread his warm bread with socks.") than for congruent words ("He spread his warm bread with butter.") in typically developing individuals (Kutas & Hillyard, 1980). Interestingly, larger brain activation was also found for unexpected semantically congruent words (e.g., "He spread his warm bread with jam.") than for expected congruent words in TDs. Nevertheless, autistic individuals are less surprised when prediction is violated (Lawson et al., 2017). In other words, contrary to controls, autistic individuals show reduced context sensitivity when presented with unexpected words (Dunn et al., 1999).

Intriguingly, the understanding of the context in other domains such as visual (Ego et al., 2016) and auditory (Ruiz-Martínez et al., 2020) seems to be either intact (Randeniya et al., 2022) or enhanced (Remington & Fairnie, 2017) in autism compared to the linguistic domain. Neuroimaging studies have suggested that autistic individuals do not differentiate from their typically developing counterparts when reacting to expectation violation on auditory prediction tasks (Barzy et al., 2019) but are less influenced by global context than controls (Goris et al., 2018). Yet, behavioural studies suggest that autistic individuals show a superior ability to reproduce atonal melodies (Applebaum et al., 1979) and enhanced abilities to discriminate embedded melodies more accurately than controls do (Bouvet et al., 2016), possibly due to their often superior memory for melodies (Weiss et al., 2021). Such inconsistencies might be a result of using different tasks to measure prediction (pure tones arising from high or low uncertainty contexts in Randeniya et al., 2022 versus detecting unexpected and expected sounds in Remington & Fairnie, 2017).

Investigating melodic and linguistic expectancy in autism

Predicting upcoming language is more difficult if the upcoming words are not expected. When thinking about the sentence ‘The piano was out of...,’ it is plausible that most people would think of the word ‘tune’ as the first word that crosses their minds to complete the sentence (Connolly & Phillips, 1994). This means that we rely on lexical information (i.e., “out of”) to predict the upcoming information (Elman, 2009). Such a technique was first introduced by Taylor (1953), who used the term ‘cloze probability’ for the percentage of people responding to the same word to a specific sentence stem. In this case, its cloze probability would be 0.85 meaning that from a pool of participants, 85 percent of them replied with ‘tune’ (Bloom & Fischler, 1980).

Typically developing individuals find cloze tasks quite intuitive and easy to complete (Fogel et al., 2015), whereas autism has been described as a “disorder of prediction” (Sinha et al., 2014) based on correlates of its diagnostic criteria. According to this hypothesis, due to autistic individuals' insistence on sameness, sensory hypersensitivity, and difficulties interacting with dynamic objects, in turn, they then have difficulties predicting future events and adapting to a new routine. This is in line with studies finding that autistic participants show impairment in openended tasks (White et al., 2009) where they produce sentence-appropriate completions but not semantically appropriate completions (Frith & Snowling, 1983). Research has consistently shown that autistic individuals have reduced sensitivity to the semantic context which is often associated with language delay (Ahtam et al., 2020).

According to The Weak Central Coherence (WCC) theory of autism (Frith, 1989; Happé, 1999; Happé & Frith, 2006), autistic individuals have a cognitive style where they tend to focus on specific details, rather than on the integration of information in its global context. Previous research extensively studied WCC in autism across different domains, such as visuospatial (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001), auditory (e.g., Bonnel et al., 2003) and linguistic (e.g., Happé, 1997). These studies supported the view of WCC by either confirming superior detail-focused processing (Bonnel et al., 2003) or reduced integration of context in autistic individuals (Frith & Snowling, 1983; Happé, 1997).

Integrating context comes particularly useful in everyday communication where upcoming words may be ambiguous (Happé, 1997), making it more demanding to use linguistic context effectively. Studies consistently report that autistic individuals tend to make more errors and synthesise the linguistic context less successfully than controls do (Jolliffe & Baron-Cohen, 1999, 2000; Wahlberg & Magliano, 2004; Alcántara et al., 2004). However, some researchers argued that complex verbal stimuli coupled with low general verbal abilities (López & Leekam, 2003) are key factors that determine whether autistic individuals would show insensitivity to global context or not. In other words, possessing autism diagnosis is not a universal predictor of having difficulties with integrating linguistic information (Hoy et al., 2004).

It was not until the late 1900s and early 2000s that researchers started investigating cloze probabilities in language using Sentence Completion Task (SCT) and creating norms for American (Bloom & Fischler, 1980) and British native speakers (Arcuri et al., 2001). Such studies created an opportunity to use the norms for other purposes, including testing clinical populations. Indeed, SCT used to be used in clinical settings as a reading comprehension tool (Shanahan et al., 1982) in autistic children (Snowling & Frith, 1986).

Previous studies that used SCT in autistic participants have either used The Hayling Test (e.g., Robinson et al., 2009), other standardized tests such as Events from the Past Test (SCEPT) (Raes et al., 2007; Crane et al., 2013), or Clinical Evaluation of Language Fundamentals (CELFPreschool, Semel et al., 1992; CELF-3, Semel et al., 1995; CELF-4, Semel et al., 2003 in Condouris et al., 2003; Lewis et al., 2007). Results showed deficits in the inhibition of prepotent responses (Robinson et al., 2009, Spitzer et al., 2017), impairments when making social inferences (Zimmerman et al., 2016) and longer reaction time in autistic individuals (Spitzer et al., 2017). It has come to attention that autistic individuals particularly find it difficult to process sentences that contain mental state verbs such as *think* or *remember* (e.g., Baron-Cohen et al., 1994; Kelley et al., 2006; Tager-Flusberg, 1992). This is in line with studies reporting poorer context integration in autism due to ToM deficits (Happé, 1997).

Similar to language prediction, cloze probability can also be used to measure melodic expectancy. For instance, many people would recognize an instrumental version of ‘Twinkle, Twinkle, little star’ and would be able to complete the melody by humming it. However, it was not until 2015 with the work of Fogel et al., that melodic cloze norms were created. This was the first study to ‘quantify’ participants’ responses in a melodic expectancy task. Fogel et al. (2015) used 45 short novel melodic stems divided in an either ‘authentic cadence’ (AC) or ‘non-cadence’ (NC), where AC stems were designed to create a strong expectation (with constraint >69%), and NC were designed not to create a strong expectation. Typically developing adults produced continuations that were significantly more constrained in the AC stems when compared to the NC stems. The results have also shown variability in participants' responses where some NC stems were perceived as equally or as greatly constraining as AC stems. This is in line with studies arguing that there are large levels of subjectivity in melodic expectancy due to probabilistic beliefs about upcoming notes (Morgan et al., 2019).

Although enhanced auditory abilities in autism are often reported (e.g., Mottron et al., 2000), surprisingly a small number of studies investigated melodic expectancy in autistic individuals. Previous studies that investigated expectancy in typically developed individuals have either asked their participants to sing a continuation of a 2-tone stimulus (Carlsen, 1981; Schellenberg et al., 2002) or to compose a melody using a musical instrument such as a piano (Thompson et al., 1997). On the other hand, studies that investigated autistic participants have used various methods such as solving a musical puzzle that creates a melody (Quintin et al., 2013), or using cloze tasks as part of the intervention program (Chenausky et al., 2016). Such studies suggested that autistic individuals are equally able to create and replicate musical structures as controls (Quintin et al., 2013) and that minimally verbal autistic children can learn spoken language as part of intonation based treatment (Chenausky et al., 2016). Other studies reported no differences between controls and autistic individuals in musical ability, memory, reproduction, creativity, or interest and emotional responsivity to music (Bhatara et al., 2013) and no group differences when judging the target tones relating to the harmonic context at both global and local levels (Heaton et al., 2007).

Some studies investigated expectancy by measuring participants' Reaction Time (RT) and reported that stems with higher cloze probability are processed faster (Staub et al., 2015) confirming that sentence-congruent completions take less time (Stanovich & West, 1983). However, there are some inconsistencies when it comes to RT in autistic participants. Some studies reported that RT in autistic individuals is less influenced by the target predictability (e.g., Lawson et al., 2017; Thillay et al., 2016), whereas some studies reported increased influence on RT by predictability (Kunchulia et al, 2017; Deschrijver et al., 2016). Such a discrepancy can be explained by the differences in defining predictability as none of these studies used cloze probability as a measure of predictability (e.g., predictable vs. random stimuli in Thillay et al., 2016). Irrelevant of how cloze probability affects autistic individuals' RT, studies agree that autistic individuals tend to have longer RT when arranging words and sentences (Jolliffe & BaronCohen, 2000) and take longer to evaluate sentence interpretation (Howard et al., 2017). On the contrary, the results in the auditory domain are less consistent. Studies reported various findings; ranging from faster RT in the autism group (e.g., Oades et al., 1988) whilst reporting faster RT only in specific conditions (e.g., stimuli delay condition in Kwakye et al., 2011), faster RTs in controls compared to the autism group (Williams et al., 2013), and no-group differences (Stewart et al., 2016).

Apart from completion tasks and participants' RT, expectancy can also be measured using perceptual tasks where participants are asked to rate (e.g., on a scale of 1-7) the expectancy of the last note/word of a melody/sentence. Such studies reported higher ratings for highly probable notes when compared to less probable notes (Pearce et al., 2009; Schellenberg, 1996; Schmuckler, 1989; Krumhansl et al., 1999), and higher ratings for highly probable words than less probable words (Federmeier & Kutas, 1999). In a study conducted by Featherstone, Waterman, and Morrison (2012) participants' ratings were assessed in three conditions on congruence (congruous, incongruous–resolved, incongruous–unresolved) using four stimulus types (harmony, rhythm, semantics, syntax). Results showed that participants' ratings exhibited stronger trends in language, when compared to music. This could be explained by the 'constraint-based model' (McRae et al., 1998) where humans process language in a competitive way ('*immediate incorporation of all available information in creation of the final output*', McDonald, 1994) whereas this is more subjective in music processing.

4.2 Aims: Experiment 3.1

To our knowledge, none of the previous studies has investigated the effects of cloze probability by using closely matched stimuli in both linguistic and melodic tasks and comparing the performance between controls and autistic individuals. In addition, the study brings novelty to the field as we also measured participants' RTs and their perceptual ratings after completing cloze tasks. This created an opportunity to draw conclusions between production and perceptual processing in autism across linguistic and melodic domains. Our research questions are outlined below.

Completion tasks

It was of interest to investigate the following: 1) Will there be any group differences in the number of responses that are the most frequent according to the norms on the Sentence Cloze Task depending on the high vs low expectancy condition? 2) Will there be any group differences in the number of responses that are the most frequent according to the norms on the Melody Cloze task depending on the high vs low expectancy condition?

Perceptual tasks

We wanted to investigate participants' ratings on a Likert scale (1-7) while rating completed sentences and melodies (''How well do you think the last word/note completes the sentence/melody?"). Thus, we wanted to test the following: 1) Will there be any group difference on participants' ratings on the Sentence Perceptual Task depending on the high vs low expectancy condition? 2) Will there be any group difference on participants' ratings on the Melody Perceptual Task depending on the high vs low expectancy condition?

Reaction time (RT)

Finally, it was also of interest to explore whether there would be any group difference in participants' RTs by testing the following: Will there be any group difference in participants' RTs between MCT and SCT depending on the high vs low expectancy condition?

Hypotheses

The hypotheses were the following:

1. Controls will produce a higher number of responses that are the most frequent according to the norms on the Sentence Completion Task when compared to autistic individuals.

Autistic participants will produce a higher number of responses that are the most frequent according to the norms on the Melody Completion Task than control participants.

2. Overall, participants will rate how well the last word fits in complete Sentences higher than how well the last note fits in complete Melodies. It was exploratory to see whether there will be an interaction between group differences and the Sentence/Melody tasks on participants' ratings.
3. It was exploratory to see if participants' RTs will differ when producing the last word in the Sentence Completion Task, compared to producing the last note in the Melody Completion task.
4. It was predicted that controls will have quicker RTs on the Sentence Completion Task when compared to autistic individuals. However, it was exploratory to see if there would be any group differences on participants' RTs on the Melody Completion Task.
5. Both groups will perform better in high expectancy condition compared to low expectancy condition, across all tasks.

4.3 Method: Experiment 3.1

Participants

The same pool of participants from Study 1 took part in the study. Participants were 42 controls (13 males) between 14 and 56 years of age (*M* = 26.05, *SD* = 10.19) and 21 autistic individuals (10 males) between 13 and 58 years of age (*M* = 32.38, *SD*= 16.02) and were all British English native speakers. The groups did not differ on any of the background measure apart from the AQ where autistic individuals had significantly higher score than controls did ($p < .01$).

Materials

Sentence Completion Task (SCT)

Sentence stems were generated from Bloom and Fischler (1980) and Arcuri et al. (2001) studies

(Appendix B). There were 90 sentence stems overall, which were split in half based on the type of response they are likely to produce (high vs. low probable) generated by only one word. Another block of 14 sentences was used in Experiment 2 (Booth & Happé, 2010).

Melody Completion task (MCT)

Novel piano stems were adopted from Fogel et al. (2015), where each stem was 5-9 notes long. Melodic stems were divided in authentic cadence (AC) vs non-authentic cadence (NC) condition (for further details see Fogel et al., 2015); where in AC condition they were designed to call for a highly probable answer, whereas in NC condition they were designed not to call for a highly probable continuation.

Pitch Matching Task (PMT)

Prior to completing MCT, participants heard eight individual tones and were asked to sing them back (Pitch Matching Task). As in the original study (Fogel et al., 2015), this was used to evaluate participants' singing accuracy. However, none of the participants were excluded based on inaccurate singing as we were not interested in professional musicians' performances. Fogel et al. (2015) used an exclusion criterion where participants who sang responses at least 25% of the trials that were more than 40 cents (logarithmic unit of measure used for musical intervals) away from the nearest semitone were excluded from the study. Overall, participants in the current study performed quite well on the Pitch Matching Task as their responses were within 50 cents from the nearest semitone.

Sentence and Melody perceptual tasks

After completing both SCT and MCT, participants were presented with a ''full version' of complete sentences and melodies and were asked to rate how well they think the last word/note fits the sentence/melody (Likert scale; 1- very bad, 7- very well).

Procedure

The final version of the stimuli was created as to match the number of syllables of the linguistic stems next to the number of notes for its pair melodic stem. Moreover, both linguistic and melodic stems were matched on the type of response they are likely to yield (high vs. low probable). For example, for a melodic stem which is comprised of nine notes, and its probability of producing the specific continuation is 0.8 – a sentence stem comprised of nine syllables was used, with a response probability within 0.8 +/- 0.05 range.

All stimuli were played to participants over a computer speaker at a comfortable listening volume in a sound attenuated room. The experimental tasks were presented using the PsychoPy program, and all completion responses were recoded as .wav files, whereas perceptual data was automatically saved as an xlsx. file.

For the SCT, participants were told to produce a single word after they hear the recording of each stem, as to complete the sentence. Participants' responses were recorded for five seconds to produce the answer. There were eight sentences for the practice trials, which took about 5 minutes to complete. The 45 experimental trials took about 10-15 minutes to complete.

For the MCT, participants were asked to "sing the note you think comes next" after hearing the beginnings of some piano stems. In addition, participants were instructed to continue the melody on the syllable 'la'. Participants started the experiment by pressing a button and after each stem the instruction 'Sing' would appear on the screen. Five seconds were provided for the sung continuation. As to familiarize the participants with the task, there was a block of practice trials prior to the experiment, which took about 5 minutes to complete. It took approximately 10-15 minutes to complete all 45 experimental trials.

In total, there were 90 language stems (high vs. low probable response), and 90 melodic stems (AC vs NC condition). Both language and melody stimuli were presented randomly. Using a Latin square design, participants only listened to half of the stimuli. Therefore, each participant was given 45 linguistic and 45 matched melodic stems to complete and was later asked to rate the same

45 “full” sentences and 45 melodies on a Likert scale (1; very bad - 7; very well), to rate how well the last word/note fits the sentence/melody. On average, each perceptual task (linguistic/melodic) took about 10 minutes to complete.

Design

For both SCT and MCT participants’ responses were categorized into four groups: a) The most frequent word(s)/note(s) according to the norms b) Any of the less frequent words/notes according to the norms c) A novel word/note that has not been reported in the norms and d) No response. To obtain the notes produced by our participants, the mean fundamental frequency of the sung note was extracted, using Praat (Boersma, 2001). As to define the pitch of the sung note, we rounded the measured mean fundamental frequency to the closest semitone in the Western chromatic scale, with the deviation from the frequency of this chromatic scale tone recorded. All responses were generalized across octaves. Participants’ RTs were measured during Sentence/Melody completion tasks using Praat (Boersma, 2001).

4.4 Results: Experiment 3.1

Descriptive data

As in Study 1, all participants were pre-screened on receptive vocabulary and abstract reasoning to take part in the study. Participants’ demographic information along with background measures are equal to those reported in Study 1. Data for the Pitch Matching task was missing for one autistic participant. There was no statistically significant difference between autistic individuals (M = 20.95, SD = 7.52) and controls (M = 22.33, SD = 7.6, t (61) = -0.67, p = .51) on the Pitch Matching task.

Data analysis

Statistical tests and plots were done in SPSS. Performance on Production tasks (Sentence/Melody completion tasks) was categorized into 4 categories: 1- answer (word/note) matching the most frequent answer from the norms, 2- any less frequent answer from the norms, 3- new answer that is not part of the norms, 4- NA. Consequently, these four categories were then analysed using a chi-square test where each completion task (sentence/melody) was split into high vs low expectancy condition. Thus, chi-square tests were conducted for SCT high/low condition, MCT high/low condition, and overall chi-square (considering both expectancy levels) for each SCT and MCT. Although the data were not independent, it was decided to run chi-square analyses, as we were interested in seeing how different conditions may relate to participants' responses across four possible categories (e.g., logistic regression would require two categories only). To adjust for multiple comparisons, Bonferroni correction was applied.

To measure performance on Perceptual tasks (Sentence/Melody rating task), mixed ANOVA was conducted to see if the groups differed in their ratings across tasks and conditions: Group (Autistic vs Control) x Task (Sentences vs Melodies) x Condition (High vs Low expectancy). Another mixed ANOVA was conducted for participants' RT analysis to see if the groups differed in their RT across the tasks and conditions: Group (Autistic vs Control) x Task (Sentences vs Melodies) x Condition (High vs Low expectancy).

Melody Cloze Task

Participants' responses were put in four categories: The most frequent response according to the norms (Fogel et al., 2015), Less frequent response according to the norms, Novel response (not part of the norms), and NA (no answer). Overall, only two responses were noted under NA category. Therefore, this category was removed from any subsequent analysis as it was inappropriate for conducting a chi-square test of independence ($N<5$).

Chi-square test: High expectancy condition

A chi-square for High probability condition was conducted to compare the frequencies of three categories of responses (The most frequent, Less frequent, and Novel response) between autistic participants and controls. The chi-square test of independence has shown a significant association between the type of the response and the group, X^2 (2, N = 62) = 6.56, p = .04, φ = .069.

To perform post hoc analyses, a procedure of *adjusted standardized residuals* was followed, where an absolute value of -/+ 2 meant that there is a statistically significant difference in a cell (Sharpe, 2015). To account for multiple tests, a Bonferroni correction was applied by dividing the alpha level by the number of tests and comparing the adjusted residual to a new critical value. In this case, the alpha level was divided by six, resulting in a new critical value of 2.9. However, no cell reached statistical significance according to this criterion. Using Delucchi's (1993) method, it can be argued that the largest difference between groups was observed in the frequencies of 'The most frequent' responses, as its standardized residual was the highest (2.4) compared to the other two (2.1 and 0.5, respectively), but this was not statistically significant. Rather, the difference in this particular category has driven the total chi-square to reach statistical significance.

Chi-square test: Low expectancy condition

A chi-square for Low probability condition was conducted to compare the frequencies of three categories of responses (The most frequent, Less frequent, and Novel response) between autistic participants and controls. The chi-square test of independence has shown a non-significant association between the type of the responses and the group, X^2 (2, N = 62) = 0.53, p = .77, φ = .020.

Chi-square test: Total across conditions (High vs Low expectancy)

The overall chi-square has shown a non-significant association between the type of the responses and the group, X^2 (2, N = 62) =5.81, p = .05, φ = .046 (see Table 4.1, and Figures 4.1 and 4.2 for further details).

Table 4.1

*Group * Category * Constraint Crosstabulation*

Constraint				Category: Novel response	Category: Less frequent	Category: The most frequent	Total
High probability	Group	TD	Count	290a	266a, b	413b	969
			Expected Count	273.7	261.9	433.4	969.0
			Adjusted Residual	2.1	.5	-2.4	
		ASD	Count	104a	111a, b	211b	426
			Expected Count	120.3	115.1	190.6	426.0
			Adjusted Residual	-2.1	-.5	2.4	
	Total		Count	394	377	624	1395
			Expected Count	394.0	377.0	624.0	1395.0
Low probability	Group	TD	Count	251a	531a	184a	966
			Expected Count	247.6	529.8	188.6	966.0
			Adjusted Residual	.5	.1	-.7	
		ASD	Count	106a	233a	88a	427
			Expected Count	109.4	234.2	83.4	427.0
			Adjusted Residual	-.5	-.1	.7	
	Total		Count	357	764	272	1393
			Expected Count	357.0	764.0	272.0	1393.0
Total	Group	TD	Count	541a	797a	597a	1935
			Expected Count	521.2	791.9	621.9	1935.0
			Adjusted Residual	1.8	.4	-2.2	
		ASD	Count	210a	344a	299a	853

	Expected Count	229.8	349.1	274.1	853.0
	Adjusted Residual	-1.8	-.4	2.2	
Total	Count	751	1141	896	2788
	Expected Count	751.0	1141.0	896.0	2788.0

Each subscript letter denotes a subset of Category categories whose column proportions do not differ significantly from each other at the .05 level.

Figure 4.1

Participants' production responses (in percentages) on the MCT in high expectancy condition

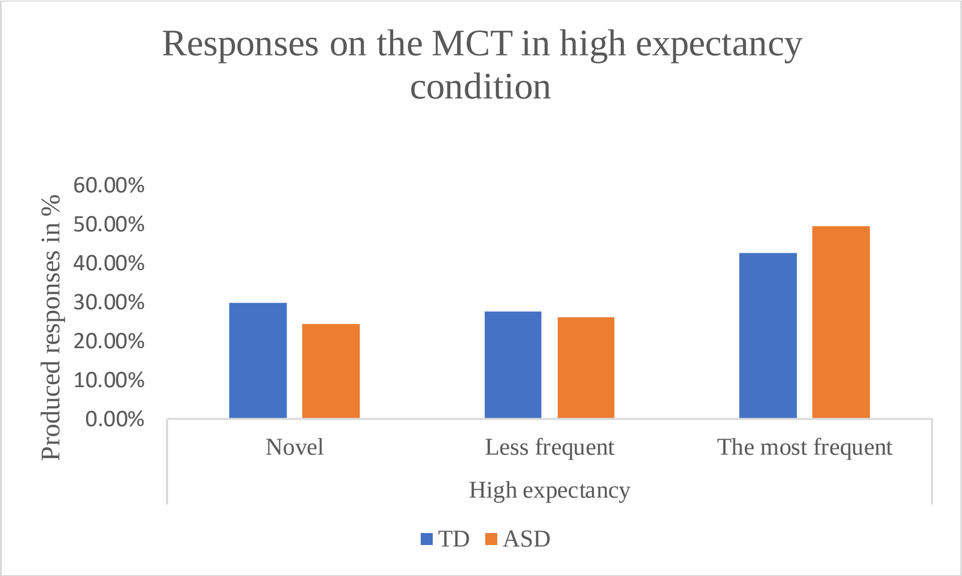
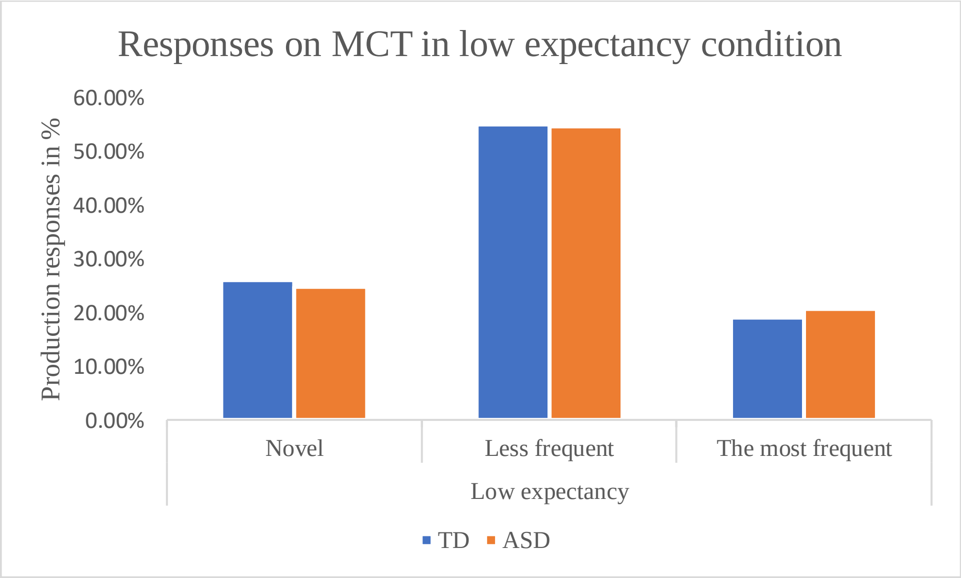


Figure 4.2

Participants' production responses (in percentages) on the MCT in low expectancy condition



Sentence Cloze Task

Chi-square test: High expectancy condition

A chi-square for High probability condition was conducted to compare the frequencies of four categories of responses (The most frequent, Less frequent, Novel response, and NA) between autistic participants and controls. The chi-square test of independence has shown a non-significant association between the type of the response and the group, X^2 (3, N = 62) = 5.33, p = .15, φ = .061.

Chi-square test: Low expectancy condition

A chi-square for High probability condition was conducted to compare the frequencies of four categories of responses (The most frequent, Less frequent, Novel response, and NA) between autistic participants and controls. The chi-square test of independence has shown a non-significant association between the type of the response and the group, X^2 (3, N = 62) = 4.82, p = .19, φ = .058.

Chi-square test: Total across conditions (High vs Low expectancy)

The overall chi-square has shown a significant association between the type of the responses and the group, X^2 (2, N = 62) = 8.12, p = .04, φ = .053. To account for multiple tests, the alpha level was divided by eight, resulting in a new critical value of 2.95. However, no cell reached statistical significance according to this criterion. Using Delucchi's (1993) method, it can be argued that the largest difference between groups was observed in the frequencies of 'NA' responses, as its standardized residual was the highest (2.8) but this was not statistically significant (see Table 4.2, and Figures 4.3 and 4.4 for further details).

Table 4.2

*Group * Category * Constraint Crosstabulation*

Constraint				Category: NA	Category: Novel response	Category: Less frequent	Category: The most frequent	Total
High probability	Group	TD	Count	19_{a}	314_{a}	160_{a}	498_{a}	991
			Adjusted Residual	-1.9	-.5	-.7	1.6	
		ASD	Count	16_{a}	148_{a}	79_{a}	205_{a}	448
			Adjusted Residual	1.9	.5	.7	-1.6	
	Total		Count	35	462	239	703	1439
Low probability	Group	TD	Count	10_{a}	363_{a}	330_{a}	286_{a} -	989
			Adjusted Residual	-2.1	.8	.1	.4	
		ASD	Count	11_{a}	156_{a}	150_{a}	135_{a}	452
			Adjusted Residual	2.1	-.8	-.1	.4	
	Total		Count	21	519	480	421	1441
Total	Group	TD	Count	29_{a}	677_{b}	$490_{a, b}$	784_{b}	1980
			Adjusted Residual	-2.8	.2	-.4	.9	
		ASD	Count	27_{a}	304_{b}	$229_{a, b}$	340_{b}	900
			Adjusted Residual	2.8	-.2	.4	-.9	
	Total		Count	56	981	719	1124	2880

Each subscript letter denotes a subset of Category categories whose column proportions do not differ significantly from each other at the .05 level.

Figure 4.3

Participants' production responses (in percentages) on the SCT in high expectancy condition

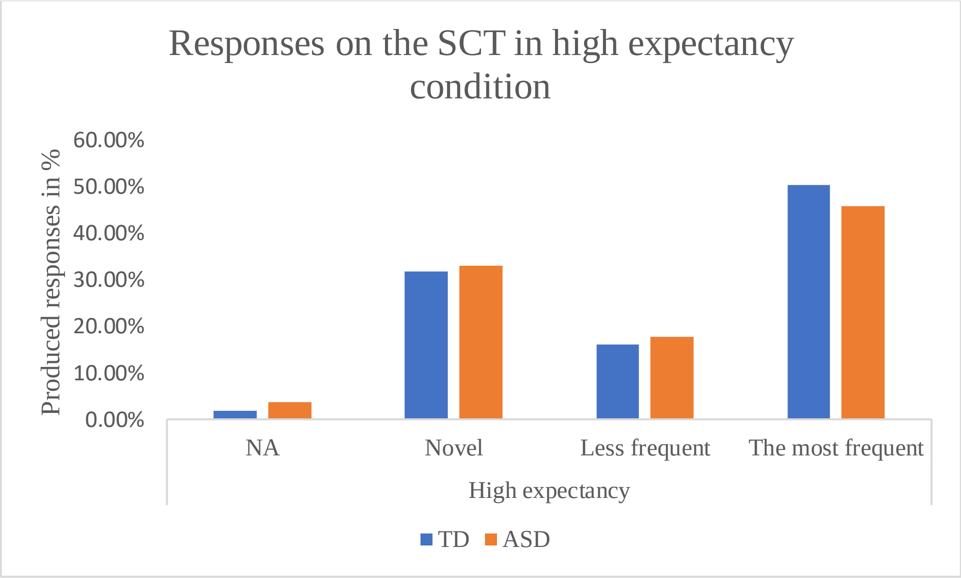
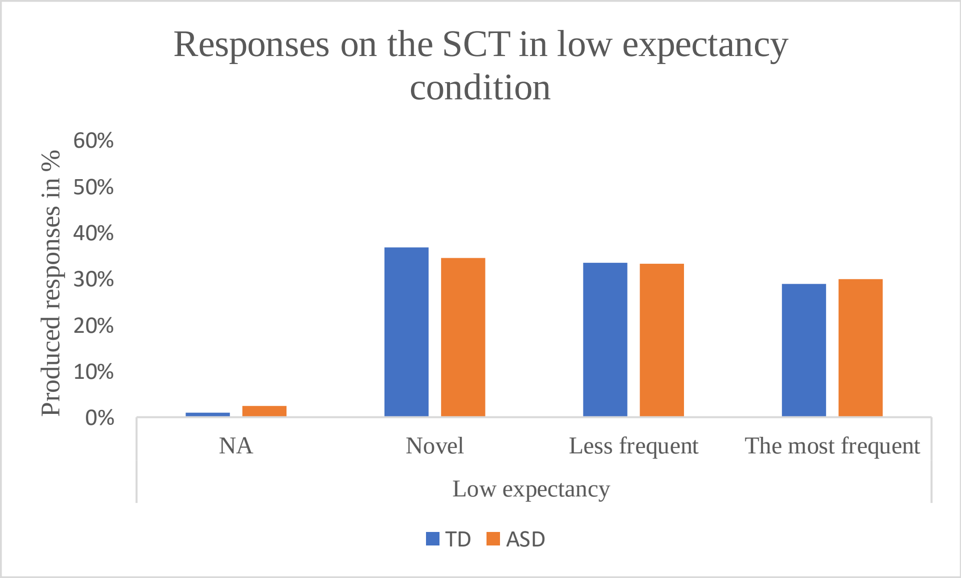


Figure 4.4

Participants' production responses (in percentages) on the SCT in low expectancy condition



Perceptual tasks: Group (Autistic vs Control) x Task (Sentences vs Melodies) x Condition (High vs Low expectancy) ANOVA

To see whether the groups (Autistic vs Control; between subject) differed in their ratings on a Likert scale (1-7) across two tasks (Sentences vs Melodies; within subject) and two conditions (High vs Low expectancy; within subject), a mixed ANOVA was conducted in SPSS. Since Mauchly's Test of Sphericity was statistically significant ($p < .001$), a Greenhouse-Geisser corrected analysis in the Tests of Within-Subjects Effects was used to interpret the main effects of the Task and the Condition.

Task

There was a statistically significant main effect of the Task (F (1,59) = 116.77, $p < .001$, η_p^2=0.664). Participants rated complete sentences (*M* = 6.65, *SD* = 0.39) significantly higher than complete melodies (*M* = 5.49, *SD* = 1.14).

Condition

There was a statistically significant main effect of the Condition (F (1,59) = 111.77, $p < .001$, η_p^2=0.654), where participants rated complete sentences and melodies significantly higher in the High expectancy condition (*M* = 6.44, *SD* = 0.68), when compared to the Low expectancy condition (*M* = 5.71, *SD* =1.17).

Group

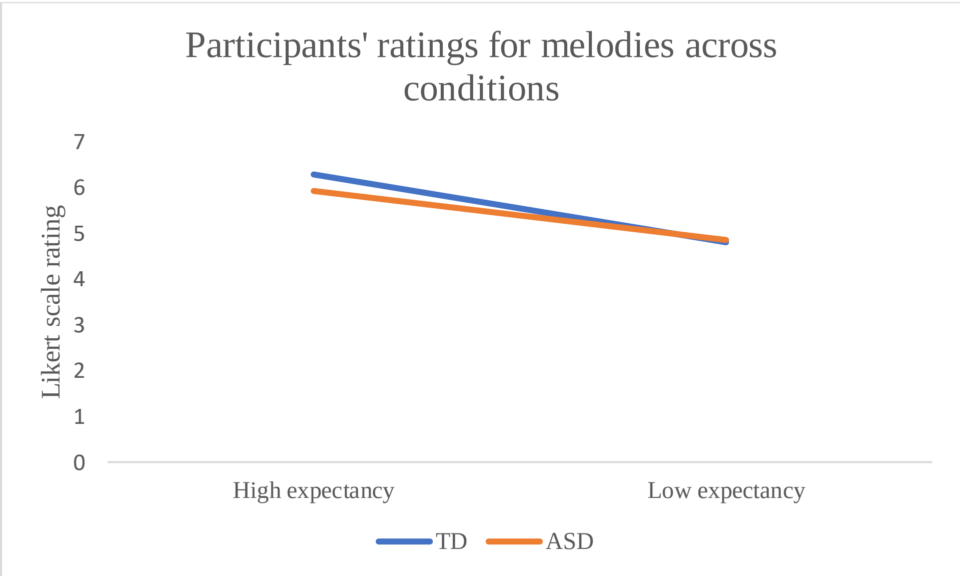
The groups did not differ in their ratings across the tasks (Complete sentences vs complete melodies) nor the conditions (High vs Low expectancy), F (1,59) = 0.75, p = .39, η_p^2=0.013.

Interactions

Interaction between the Group and the Task was not statistically significant (F (1,59) = 0.16, p = .70, η_p^2=0.003), whereas the interaction between the Group and the Condition (F (1,59) = 3.86, p = .05, η_p^2=0.061) was marginally significant. To follow up this trend, a paired t-test has shown that this interaction was driven by a larger discrepancy in controls' rating melodies in High vs Low expectancy condition whereas this difference was smaller in autistic participants (see Figure 4.5).

Figure 4.5

Participants' ratings for complete melodies in High vs Low expectancy conditions



In addition, there was a statistically significant interaction between the Task and the Condition, *F* (1,59) = 83.10, $p< .001$, $\eta_p^2=0.695$). Paired t-tests have confirmed that participants rated complete sentences higher in the High expectancy condition compared to Low expectancy condition, *t* (61) = 4.07, $p< .001$, *d* = 0.575. The same pattern was observed for rating complete melodies, *t* (60) = 11.47, $p< .001$, *d* = 1.469 (see Table 4.3 and Fig 4.6).

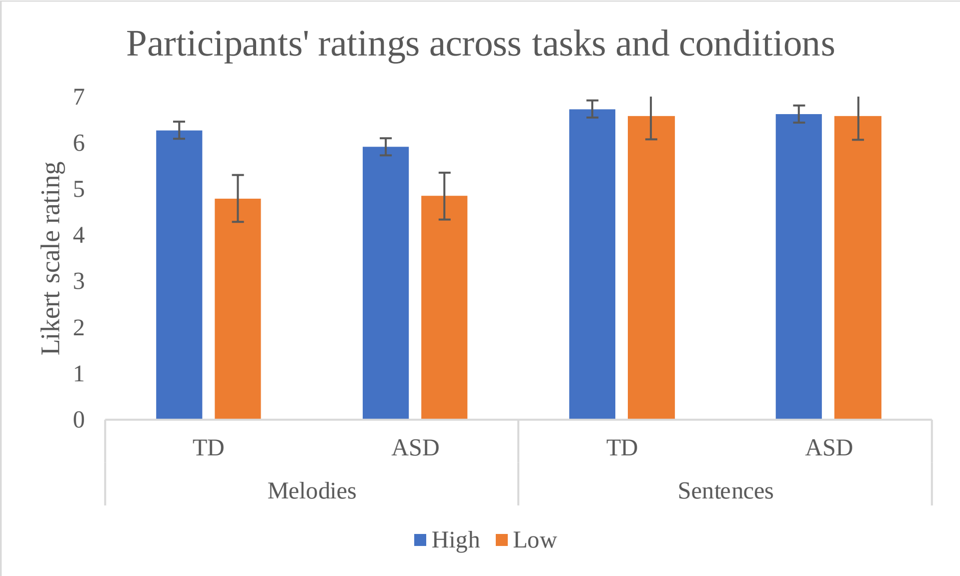
Table 4.3

Participants' ratings across tasks (Melodies vs Sentences) and conditions (High vs Low expectancy)

Task	Condition	Group	*N*	*M*	*SD*
Melodies	High	TD	42	6.28	0.59
		ASD	19	5.92	1.12
Melodies	Low	TD	42	4.80	0.98
		ASD	19	4.85	1.13
Sentences	High	TD	43	6.74	0.27
		ASD	19	6.63	0.52
Sentences	Low	TD	43	6.59	0.35
		ASD	19	6.58	0.54

Figure 4.6

Participants' ratings across tasks (melodies vs sentences) and conditions (high vs low expectancy)



Reaction Time (RT) data: Group (Autistic vs Control) x Task (Sentences vs Melodies) x Condition (High vs Low expectancy) ANOVA

To see whether the groups (Autistic vs Control; between subject) differed in their RTs when producing a final word/note across two tasks (Sentences vs Melodies; within subject) and two conditions (High vs Low expectancy; within subject), a mixed ANOVA was conducted in SPSS. Since Mauchly's Test of Sphericity was statistically significant (p = .02), a Greenhouse-Geisser corrected analysis in the Tests of Within-Subjects Effects was used to interpret the main effects of the Task and the Condition.

Group

The groups did not differ in their RTs across the tasks (Completing sentences vs completing melodies) between the two conditions (High vs Low expectancy), *F* (1,60) = 0.05 s, *p* = .82, η_p^2=0.001.

Task

There was a statistically significant main effect of the Task (*F* (1,60) = 12.64, *p*< .001, η_p^2=0.155), where on average, participants produced the final note (*M* = 0.44 s, *SD*= 0.51) significantly quicker when compared to the time it took them to produce the final word (*M* = 0.76 s, *SD*= 0.55) (see Table 4.4 and Figure 4.7).

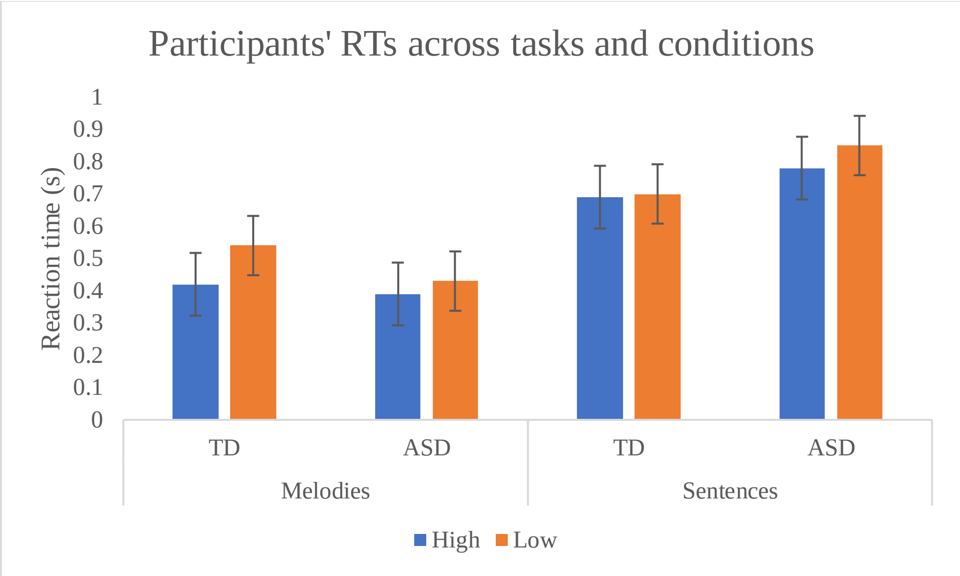
Table 4.4

Descriptive Statistics: participants' RTs across tasks and conditions

	Group	*M*	*SD*	*N*
Sentences High expectancy	TD	0.69	0.54	43
	ASD	0.78	0.54	19
Sentences Low expectancy	TD	0.70	0.51	43
	ASD	0.85	0.60	19
Melodies High expectancy	TD	0.42	0.41	43
	ASD	0.39	0.53	19
Melodies Low expectancy	TD	0.54	0.55	43
	ASD	0.43	0.57	19

Figure 4.7

Participants' RTs across tasks (Sentences vs Melodies) and conditions (High vs Low expectancy)



Condition

There was a statistically significant main effect of the Condition (F (1,60) = 12.14, $p< .001$, η_p^2=0.113), where participants took significantly less time to produce a final note (M = 0.41 s, SD = 0.44) and a final word (M = 0.72 s, SD = 0.54) in the High expectancy condition, when compared to the Low expectancy condition (M = 0.50 s, SD =0.55, and M = 0.74 s, SD = 0.54, respectively).

Interactions

Interaction between the Group and the Task was not statistically significant (F (1,60) = 1.12, p = .29, η_p^2=0.169), as well as the interaction between the Group and the Condition, (F (1,60) = 0.03, p = .86, η_p^2=0.096). The interaction between the Task and the Condition was not statistically significant either (F (1,60) = 2.10, p = 0.15).

However, a three-way interaction between the Task and the Condition and the Group was statistically significant (F (1,60) = 5.71, p = .02, η_p^2=0.011). To explain the interaction, paired t-tests were conducted to determine which Group differed in their RTs across Tasks and Conditions.

It was found that the significant interaction was driven by controls' RTs when completing melodies. In other words, controls took significantly more time to complete the melodies in the Low expectancy condition (*M* = 0.54 s, *SD* = 0.55), when compared to the High expectancy condition (*M* = 0.42 s, *SD* = 0.41, $t\ (42) = 4.17$, $p < .001$, $d = 0.636$).

4.5 Discussion: Experiment 3.1

The present study was designed to investigate the effects of high versus low expectancy conditions, using Sentence Cloze Task (producing the final word) and Melody Cloze Task (producing the final note), as well as corresponding perceptual tasks. As expected, it was found that autistic individuals produced significantly more ‘the most frequent’ responses on the MCT but this was only the case in the high expectancy and not in the low expectancy condition, when compared to controls. Once the Bonferroni correction was applied, this difference was not statistically significant.

Contrary to what was expected, both groups performed equally well on the SCT in both high and low expectancy conditions. Overall, autistic participants produced significantly more NA responses than controls in high- and low-expectancy conditions. However, this difference was not significant after applying the Bonferroni correction. The groups did not differ in their ratings across the tasks (complete sentences vs complete melodies) nor the conditions (high vs low expectancy). Finally, although the groups did not differ in their RTs across the tasks or the conditions, both groups needed less time to complete melodies than sentences.

It was expected that autistic individuals would have outperformed controls on MCT, which is in line with studies reporting enhanced auditory abilities (e.g., Mottron et al., 2000), special interests in music (Grove et al., 2018), and enjoyment in musically related tasks in autism (Bhatara et al., 2013). However, this was not the case in the current study. Perhaps a specific cognitive style in autistic individuals was less evident across our expectancy conditions, which is in line with studies reporting that autistic individuals are less influenced by the cloze probability on auditory tasks than controls are (Goris et al., 2018).

Contrary to what was hypothesised, controls did not outperform autistic individuals on SCT. It is plausible that the task was not demanding enough to yield between-group differences. Current results contradict previous research suggesting that autistic individuals use semantically inappropriate words (Frith & Snowling, 1983). This result can also be related to heterogeneity in language profiles among autistic individuals (Harper-Hill et al., 2013) where some participants may show subtle differences in their linguistic abilities (e.g., scoring high on pragmatic tasks but low on structural tasks).

Although the groups did not differ on their rating between sentence and melody perceptual tasks, it was found that participants rated complete sentences higher than complete melodies. This supports previous research claiming that humans process music in a more subjective way, whereas we use a 'race-model' in language (Gompel et al., 2000). For example, a sentence ''The pizza was too hot to ..." invites the word 'eat' (cloze probability = 0.86, Arcuri et al., 2001), which in turn, would easily be rated high based on the last word having such a high expectancy. It is also plausible that the sentences were rated higher due to their familiarity to everyday situations, and sounded "correct" even in the low expectancy condition (e.g., "The Browns have never visited that place", cloze probability = 0.25, Arcuri et al., 2001).

Contradictory to what we expected, there was no difference between the groups on their Reaction Times (RTs). We expected quicker RTs in controls on the SCT, although previous literature is inconsistent about RTs in autistic participants. Some studies reported that autistic individuals' RTs tend to be less modulated by the cloze probability (Lawson et al., 2017; Thillay et al., 2016). In addition, the task was a statistically significant predictor where it was found that participants responded quicker when completing melodic stems, than completing linguistic stems. It could be that participants were thinking more about what word to use, whereas when they were asked to sing, they found the task intuitive and sang a note on "la" (Fogel et al., 2015).

Finally, as predicted, significant differences in high versus low expectancy conditions emerged. Participants performed better in high expectancy condition than in low expectancy condition, across all tasks. This is in line with studies reporting that higher probabilities invite more frequent responses (Van Petten & Luka, 2012). There were also differences in participants' RTs across conditions (i.e., quicker RT in high expectancy condition), which is in line with previous studies claiming that we process information with high expectancy quicker, compared to that information with low expectancy (Staub et al., 2015).

Limitations and future directions

For sample size (N = 63) in Study 3 (sentence/melody completion tasks; chi-square analyses), and a fixed alpha level at .05, post-hoc power calculations revealed that small ($f2 = 0.07$), medium ($f2 = 0.21$), and large ($f2 = 0.35$) group differences were detectable with a with power estimates of 0.07, 0.3, and 0.7, respectively. Thus, the study did not have adequate power to detect large group differences, nor medium or small. For the perceptual tasks (mixed ANOVA) and a fixed alpha level at .05, post-hoc power calculations revealed that small ($f2 = 0.02$), medium ($f2 = 0.15$), and large ($f2 = 0.35$) group differences were detectable with a with power estimates of 0.06, 0.65, and 0.99, respectively. In other words, this task had adequate power to detect large group differences but inadequate power to detect medium or small group differences.

We have used the norms from previous studies, based on American and British English native speakers. However, cultural differences (e.g., different completion words with the same meaning: nil vs zero) might have an impact on the level of expectancy and ideally, we would have created our own norms and then analysed the data. It would particularly be interesting to see whether autistic participants' data would produce different norms than controls' data. In addition, studies on autism tend to report that the group difference disappears if participants are individually matched on relevant background measures such as age and gender (Mottron, 2004). Further studies are warranted to explore the effects of cloze probability on linguistic and melodic tasks using larger sample size and novel norms that can be applied to an English-speaking autistic population. Lastly, such norms would have important implications for creating a music-assisted intervention program that enables better language use in autistic participants.

4.6 Aims: Experiment 3.2

As described in Experiment 1, Sentence Completion Task (SCT) seems to be a useful tool for measuring individual differences in clinical populations, including young autistic adults (Losh et al., 2009). A specific SCT that measures the WCC account is designed to invite an answer that could be considered a consequence of a specific cognitive style (Happé, 2005), whilst completing the sentence by using one word only. For instance, in a study conducted by Booth and Happé (2010), a "local" completion of the stem "In the sea, there are fish and…'' would be the word "chips", whereas the word "sharks" would be considered as a "global" completion. The results showed that autistic participants made significantly more local completions than controls did. This is in line with the current model of WCC where everyone's cognitive style lies on a continuum between strong and weak coherence, but autistic people tend to be on the weak coherence extreme end (Happé & Booth, 2008, Happé & Frith, 2006).

The main aim of Experiment 2 was to use the SCT as in the original study (Booth & Happé, 2010) by extending its work where it was of interest if the groups (controls vs autistics) would differ in the number of their responses (0- point response, 1- point response, 2-point global response, and NA) when completing the sentence stems. There are two reasons why we included NAs as a separate category: in the original study, participants were assigned one point for answers 'I don't know', which could have an impact on the overall completion score. In addition, since many participants had 'I don't know' responses in Experiment 1, it seemed necessary to include them here as a separate category as well. Succeeding the WCC account (Happé, 2005) and the results from the original study (Booth & Happé, 2010), the following was expected:

1. Autistic participants will make more local responses, odd responses, and will have a higher number of NA responses compared to controls. However, controls will have a higher number of global responses than autistic participants.
2. Autistic participants will take longer than controls while completing the sentence stems.

Thus, autistic participants' RTs will be longer than the controls' RTs.

4.7 Method: Experiment 3.2

Participants

All participants were adults and the control group consisted of 45 participants (32 females and 13 males). There were 21 autistic adults (9 females and 12 males), all of whom received a formal diagnosis of autism or Asperger syndrome by a qualified clinician using DSM-IV or DSM-5 criteria (APA, 1994).

Materials

The Sentence Completion Task (SCT) was comprised of 14 sentences and was adopted from Booth and Happé (2010) (Appendix C). Ten stems were designed to test weak central coherence, inviting participants to use a local completion, whereas other four stems were used as 'filler' stems. Filler stems were not analysed, as they were not a part of testing the WCC theory and were used as practice trials only, which took about 5 minutes to complete.

Procedure

Stimuli sentences were played to participants over a pair of computer headphones at a comfortable listening volume in a sound attenuated room. The experiment was presented using PsychoPy programme (Peirce et al., 2019), and all responses were recoded as .wav files.

Participants were instructed to produce a single word after they hear the recording of each stem, as to complete the sentence. Participants were allowed to use more than one word, if necessary, but this was not said directly unless asked by participants. Participants were given five seconds to produce the answer by speaking clearly into the microphone. On average, it took about five to seven minutes to complete the task.

Scoring

Completion score

A 3-point scoring system was adapted from the authors, with some changes made as we were interested in the number of NA responses (e.g., ‘’I don’t know.’’). In other words, participants were assigned 2 points for a globally meaningful completion that was produced; 1 point when the response was an “odd” completion to the sentence but not an obviously local completion (e.g., a repetition or local associate to another word in the sentence), and 0 points assigned to local responses. Finally, NA responses were noted down and summarized per each participant. Contrary to the original study, we included NAs as a separate category whereas in the original study, these were assigned one point. For instance, in the sentence stem ‘In the sea there are fish and..’ an answer such as ‘chips’ would be scored as a local completion, when compared to the word ‘sharks’, which would be scored as a global completion. Participants’ responses for 10 stems were manually scored, whereas the other four filler stems were used as practice trials only and were excluded from any further analysis. Placement students transcribed participants’ answers, as well as blind crosschecked between each other. The experimenter, AV, created the definitive version.

Number of local responses

As in the original study, the total number of local completions (maximum = 10) was used as a measure of local bias.

Response time (RT)

Participants’ RTs were measured using Praat (Boersma, 2001), and extracted using Excel with the help from placement student HA.

4.8 Results: Experiment 3.2

Descriptive statistics

As in previous studies, participants took part in relevant background measures. Raven's matrices scores were reported as raw scores, whereas receptive vocabulary scores were reported as standardized scores. Although 21 autistic participants and 45 controls took part in the study, some background measures' scores are missing due to either incomplete data collection (COVID-19 disruptions) or due to technical issues. The groups did not differ on any of the background measures' performance apart from the AQ where autistic participants (*M* = 38.52, *SD* = 6.74) had significantly higher autistic traits than controls did (*M* = 15.47, *SD*= 7.38, $t\ (64)= 12.14$, $p< .001$). In addition, controls were significantly younger (*M* = 24.24, *SD* = 7.35) than autistic participants (*M* = 35.90, *SD* = 17.01, $t\ (64)= 3.01$, p = .006). All data from the background measures can be found in Table 4.5.

For the purposes of presenting participants' scores descriptively, participants' overall global completion score was calculated as the sum of both 2-point and 1-point global responses. Two participants' RTs (in *Ms*) were not included in the table due to technical problems during data collection. All scores are presented in Table 4.6.

Table 4.5

Participants' background measures

Measure	Group	N	*M*	*SD*	*t*	*p*
Raven's	Autism	21	52.29	5.32		
	Control	45	52.04	3.91	.21	.84
ROWPVT-4	Autism	21	113.57	15.97		
	Control	45	106.56	13.39	1.86	.07
Musical years	Autism	21	7.05	7.39		
	Control	45	4.44	5.34	1.63	.11
Age	Autism	21	35.90	17.01		
	Control	45	24.24	7.35	3.01	.01
Digit span	Autism	19	6.84	1.71		
	Control	45	7.24	1.30	- .92	.36
Corsi Block	Autism	18	6.06	1.21		
	Control	45	6.69	1.47	-1.76	.09
The AQ	Autism	21	38.52	6.74		
	Control	45	15.47	7.38	12.14	< .001

Table 4.6

Participants' scores across different types of answers

Score	Controls		Autism group	
	M	*SD*	*M*	*SD*
Global score	16.60	2.20	15.71	3.29
Local score	0.44	0.78	0.48	0.75
NAs	0.91	0.93	1.19	1.40

Note. A maximum score was 20 points per participant. NA category was used for no responses or for 'I don't know' answers.

Association between the Group and the completion performance

A Chi-Square test of independence was performed to determine whether the groups (Autistic vs Control) differed in four different types of responses. It was found that the proportions of four completion types (2-point Global, 1-point Global, Local, NA) did not differ between autistic individuals and controls, X^2 (3, N = 66) = 3.04, p = .38, φ = 0.37.

Response time

There was no statistically significant difference between autistic participants' RTs (M = 0.08, SD = 0.03) and controls' RTs (M = 0.09 *Ms*, SD = 0.02, t (62)= -1.87, p = .07, d = 0.91).

4.9 Discussion and limitations: Experiment 3.2

In this experiment, we wanted to investigate whether there would be a difference between controls and autistic individuals on the type of response to sentences inviting a weak central coherence, while also considering participants' response time. There was no statistically significant difference between the groups in any type of score, including the response time. In the original study conducted by Booth and Happé (2010), autistic individuals had a lower completion score and more local completions, when compared to controls. Although the current study has the same pattern of results as the original study does, where on average autistic individuals had a lower Global score and higher Local score than controls did, none of this reached significance. There are several explanations that could be used to clarify the differences between the current study's results and the original study's results.

Firstly, our participants were at least 12 years old and most of them were adults, whereas in the original study, the participants' age ranged from 9 to 20 years of age. Indeed, even Booth and Happé (2010) noted that age has an impact on participants' completion scores as in their Study 1 where they tested controls only, it was found that older participants had better completion performance overall.

Secondly, our scoring system was different as we had a separate category for 'I don't know' responses (NA category), whereas Booth and Happé (2010) assigned these answers one point. Although it did not reach significance, our autistic individuals had more NA answers than controls did. Moreover, although Booth and Happé (2010) found a statistically significant higher Global scores in controls than in autistic individuals, these scores are remarkably similar to our study's scores; and in both studies both groups scored quite high (average higher than 15 out of a maximum number of 20 points). Therefore, although in the original study there was a difference between groups on the Global score, it could be said that both groups performed quite well on the task.

In addition, in the original study, participants were read aloud the stems, whereas in our study, participants were played the stems and heard them through the headphones. It is plausible that in the current study, autistic participants performed equally well as controls as they were comfortably seated in a soundproof booth, and there was no interaction with the experimenter during the task. This is in line with previous study claiming that autistic individuals seem to perform better on a task if presented on the computer than with the experimenter (Ozonoff, 1995).

Current results are in line with previous studies finding no difference in reaction time on WCC tasks between autistic individuals and controls (e.g., Booth & Happé, 2018) nor a consistent local processing bias in autism (e.g., D'Souza et al., 2016). More recent research has reported that there is not necessarily a global/local processing style/bias per se but a preference that differs from everyone to another, both in autistic individuals and non-clinical populations (Happé & Booth, 2008, Happé & Frith, 2006). Finally, it should be noted that studies whose results supported the WCC theory, primarily tested children or adolescents (e.g., Shah & Frith, 1993; Vanegas & Davidson, 2015).

For sample size (N = 66) in this study (sentence completion task; chi-square analysis), and a fixed alpha level at .05, post-hoc power calculations revealed that small (f2 = 0.07), medium (f2 = 0.21), and large (f2 = 0.35) group differences were detectable with a with power estimates of 0.07, 0.27, and 0.66, respectively. That means that the study did not have adequate power to capture large group differences, or medium/small. Further research is warranted to explore developmental trajectories in autism and how these may relate to a ‘shift’ in processing style later in life by comparing diverse types of stimuli (e.g., visual, auditory, linguistic), and using a larger sample size.

4.9.1. General discussion and future directions

In sum, in Experiment 1 it was found that autistic individuals produced significantly more ‘the most frequent’ responses on the MCT in the high expectancy but not in the low expectancy condition, when compared to controls. Although both groups performed equally well on the SCT in both high and low expectancy conditions, it was found that overall, autistic participants produced more NA responses than controls did, which drew the overall chi-square to reach statistical significance. The groups did not differ in their ratings across the tasks (complete sentences vs complete melodies) nor the conditions (high vs low expectancy). Finally, although the groups did not differ in their RTs across the tasks or the conditions, both groups needed less time to complete melodies than sentences. In Experiment 2, contrary to what was expected, autism group did not show a bias towards producing more local than global responses, and groups did not differ in their RTs when completing the sentences. It is interesting to observe a group difference where autistic individuals were more successful to produce the most frequent note in the high expectancy condition compared to controls. This is in line with studies reporting often enhanced musical abilities (Mottron et al., 2000) and a general preference and enjoyment towards melodic stimuli (Bhatara et al., 2013).

Finding no group difference across the conditions on the SCT is in line with studies reporting intact linguistic abilities in autistic individuals (e.g., Coderre et al., 2017). Nevertheless, it should be noted that the autism group produced more NA responses on the SCT. Further studies should investigate this further by including these responses as a separate category. Not providing answers as frequently as controls is in line with studies reporting reduced conversational abilities in autistic individuals (Cola et al., 2022).

Due to such mixed results in the literature, it was exploratory to see if autistic individuals will need more time than controls to complete melodies, but a surprising result was that no group differences were found in participants’ RTs when completing the sentences. It is plausible that the group difference in RTs on the SCT occurs only on more demanding tasks (Minshew et al., 1997).

The original study (Booth & Happé, 2010) reported a higher number of local completions on the SCT when compared to controls. Further studies are warranted to examine the discrepancy between the current study's null results and the original study by employing both procedures (experimenter present during the task in Both & Happé, 2010 vs participants' responses recorded without the presence of the experimenter).

In sum, the findings from Experiment 1 emphasise different abilities to integrate context in autism depending on its modality (auditory versus linguistic) and its expectancy. Current findings are in line with studies reporting intact (Randeniya et al., 2022) or enhanced abilities (Remington & Fairnie 2017) on expectancy tasks in the auditory domain, and intact processing of the linguistic context (Coderre et al., 2017). Even though the groups in the current study did not differ on the linguistic prediction task, similar to findings in Coderre et al. (2017) it could be argued that autistic individuals integrate linguistic information differently from their typically developing counterparts. In the current study, this was a result of significantly more NA responses in the autism group, which supports the notion that autistic individuals are less influenced by semantic priming (Coderre et al., 2017) or in this context word expectancy (Dunn et al., 1999). Nonetheless, the results from Experiment 2 contradict previous research supporting the WCC account (Booth & Happé, 2010). Further research is warranted to explore prediction in autism across different domains and its relation to the WCC account.

5 General discussion

5.1 Summary of findings

This thesis used a diverse range of studies to test multiple aspects of auditory and linguistic processing in autism, in particular: discrimination tasks in a foreign language, sentence repetition in English, and both melodic and linguistic production and perceptual tasks investigating expectancy. The following main hypotheses were tested:

Study 1: Autistic individuals will outperform controls on all discrimination tasks. If no group differences were found, there would be a subgroup of autistic individuals with exceptional perceptual abilities of foreign pitch.

Study 1a: If no group differences were found, there would be a subgroup of autistic individuals who possess exceptional discriminatory abilities of foreign pitch.

Study 2: Overall, controls will have a higher accuracy on SRep task, irrelevant of experimental conditions, when compared to autistic individuals.

Study 3: Controls will produce more ‘the most frequent’ responses according to the norms on the sentence completion task, whereas autistic individuals will produce more ‘the most frequent’ responses according to the norms on the melody completion task.

Study 3a: Overall, autistic individuals will produce more ‘local’ responses on the sentence completion task inviting the WCC account, compared to controls.

To address previous research limitations, this thesis incorporated stimuli from both a tone language and a non-tonal language where each task varied in its complexity (discrimination vs one word/one note production vs sentence production). Since most previous studies have focused on the imitation of speech sounds as part of their production tasks (e.g., Wang et al., 2021), this thesis aimed to use stimuli that can be applied in an everyday setting, while drawing conclusions between foreign language perceptual abilities and native language production and perceptual performance in autistic individuals. Stimuli in Study 1 were comprised of natural speech and its gliding tone analogues (non-speech), and lexical tone discrimination (words vs non-words). Study 2 used a novel stimulus comprised of 60 sentences while manipulating the effects of the Content, the Noise, and the Form. Lastly, Study 3 used both production and perceptual tasks in English using a closely matched stimuli of sentence and melody stems (low vs high expectancy), as well as complete sentences and melodies, respectively. To avoid any confounding effects, groups were matched on important background measures, such as cognitive abilities, musical training, and verbal and nonverbal short-term memory. Research questions, measures used, and findings of each experiment are summarized in Table 6.1.

Question	Measure	Finding	Answer
Study 1. Do autistic non-tonal speakers have enhanced perceptual abilities in a tone language?	Natural speech and gliding tone analogue discrimination task, and Lexical discrimination task	Comparable results between the groups	No
Study 1a. Is there a subgroup of autistic individuals who show enhanced perceptual abilities?	Natural speech and gliding tone analogue discrimination task, and the Lexical tone discrimination task	No subgroup identified	No
Study 2. Is autism associated with differences in song and sentence repetition accuracy?	SRep task: in lab setting	Comparable results between the groups	No
	SRep task: an online study	Controls had higher accuracy on the SRep than autistic participants	Yes
Study 3. Is autism associated with differences in melodic and linguistic expectancy?	Sentence Cloze task (SCT), Melody Cloze task (MCT), and Sentence/Melody Perceptual tasks	Comparable results between the groups	No
Study 3a. Is autism associated with a "local bias" when completing sentences?	Sentence Completion Task (Booth & Happé, 2010) inviting a local response (The WCC account)	Comparable results between the groups	No

Table 6.1. A summary of how each research question contributes to the general hypothesis that autistic people show enhanced perceptual abilities and/or intact/enhanced production abilities in the auditory domain, whereas in the language domain production abilities are impaired. Whether the reported data indicates as 'Yes' or 'No' response to the 'Question' column is reported in the 'Answer' column.

5.1.1 Study 1 overview: Do autistic English-speakers have enhanced tone and intonation perception in a foreign tone language?

Autistic individuals have shown exceptional perceptual abilities stimuli in the visual domain (Kopec et al., 2020), which has led researchers to investigate whether the same applies to the auditory domain (Samson et al., 2006). The primary objective of the first study in this thesis was to determine if autistic individuals have enhanced perceptual abilities in the auditory domain, as indicated by previous empirical studies. Due to the lack of lexical information (Yu et al., 2015), it was expected that autistic participants would outperform controls on perceptual tasks in a foreign language (Mandarin), but the results were comparable between the groups. In addition, since some studies reported only a subgroup of autistic individuals who possess superior perceptual abilities (e.g., Jones et al., 2009), we conducted a subgroup analysis. However, we did not identify a subgroup of autistic individuals with superior perceptual abilities of the foreign pitch. Current findings contradict previous research reporting enhanced perceptual abilities in autism (Bonnel et al., 2003; Heaton 2003; Heaton et al., 2008a) or reporting enhanced perceptual abilities in a subgroup of some autistic individuals (Jones et al., 2009).

A few explanations can be used to disentangle the findings. Firstly, previous studies that reported enhanced perceptual abilities in autistic individuals in a subgroup of autistic individuals only (Jones et al., 2009), have also noted that such individuals have a history of language delay, and emphasized that superior abilities in autism may only be present as part of the frequency discrimination task. Secondly, given the heterogeneity of autistic individuals' cognitive profiles (Torenvliet et al., 2023), it could be that the current findings are the results of individual differences among the autistic population or a subgroup of autistic individuals (e.g., Jones et al., 2009). Perhaps an increased number of trials would have grasped enhanced perceptual functioning in autistic individuals, as suggested by Millin et al. (2018) who noted that greater neural reactivity in autism occurs only after repeated stimulation, and at fixed intervals. Finally, both groups were matched on important background measures, so that there are no confounding variables that could have affected participants' performance.

More recent research investigating auditory abilities in autism supports our findings. For instance, Chen et al. (2022) confirmed that tone-speaking autistic children do not differ from typically developed children when imitating non-speech sounds, and O'Rourke et al. (2021) found no differences between autistic adults and their typically developed counterparts in the speech condition. According to a recent review (Rotschafer, 2021), the varying outcomes in the auditory abilities of autistic individuals can be attributed to developmental delays, differences in sensory processing, and co-existing conditions (e.g., Rett syndrome, Stauder et al., 2006) that impact auditory processing.

Apart from the empirical studies, the results of Study 1 also contradict both the Weak Central Coherence account, and the Enhanced Perceptual Functioning model (Mottron et al., 2006). The current results are in line with those of Plaisted et al. (2003), who suggested that superior perceptual abilities among autistic individuals might be applicable to the visual domain only. A systematic review and meta-analysis of the auditory mismatch negativity in autism explains that factors such as small sample sizes, low power, and differences in the type of stimuli used (speech vs. non-speech) could have contributed to inconsistencies in studies investigating auditory processing in autistic individuals (Schwartz et al., 2018).

Supplementary material (see Appendix D) confirms the complex processing on auditory tasks in autism. For example, controls' discriminating abilities (e.g., Lexical tone) were related to both musical training (i.e., a sum of formal/informal years of singing/playing an instrument), and their age. However, this was not observed in autistic individuals. It appears that musical training and age have a more significant impact on controls' foreign pitch perception, whereas autistic individuals tend to rely on their cognitive abilities, such as memory (e.g., Heaton, 2003). Overall, these findings support the idea of no differences on auditory tasks between controls and autistic individuals if the groups are matched on cognitive abilities (e.g., Germain et al., 2019; Globerson et al., 2015; Jones et al., 2009), which is in line with the current study. In addition, autistic traits were not related to discrimination abilities in either of the groups in the current study. Yet, Iao et al. (2018) found that social skills subscale of the AQ (Baron-Cohen et al., 2001) was associated with foreign pitch discrimination abilities. Future studies could investigate how individual differences may have an impact on auditory processing, and further explore its relationship with social abilities in autism. In turn, such studies could have important implications in common social situations for autistic individuals.

5.1.2 Study 2 overview: Is autism associated with differences in song and sentence repetition accuracy?

While Study 1 aimed to capture auditory perceptual abilities in autism, Study 2 aimed to investigate production abilities in the linguistic domain. As mentioned in the general introduction, the autistic population is especially intriguing for exploring cross-domain processing due to the literature reporting enhanced perceptual abilities across both domains (Foxton et al., 2003; Mottron et al., 2000) but often impaired linguistic production abilities (Key & D’Ambrose Slaboch, 2021). Study 2 in-lab data collection was disrupted due to COVID-19, and its results should be interpreted as preliminary only due to a small sample size. Using an online study with the same set of sentences, a statistically significant difference between the groups was found where autistic participants showed weaker accuracy on the SRep task, compared to controls. Language abilities in autistic individuals are highly heterogenous (Tager-Flusberg, 2004), and although autistic participants in the current thesis did not differ from controls in their standardized scores on receptive vocabulary, their sentence repetition accuracy was lower than controls’ accuracy. This is in line with studies reporting low performance of autistic individuals on SRep tasks whilst noting the importance of variability in their types of errors (Brynskov et al., 2016; Sukenik & Friedmann, 2018).

Broadly speaking, general language use involves structural language skills including language form (e.g., syntax) and content (semantics), as well as pragmatic language skills (appropriate use of language in different contexts) (Reindal et al., 2021). A study conducted by Volden et al. (2009) found that structural language abilities, as measured by the Clinical Evaluation of Language Fundamentals 3 (CELF-3; Semel et al., 1995), accounted for a substantial portion of the variance in pragmatic language as measured by the Test of Pragmatic Language (TOPL; Phelps-Terasaki & Phelps-Gunn 1992).

Structural language abilities are closely related to pragmatic deficits in autistic population. Nevertheless, structural abilities have been less investigated in autistic individuals. It would be of interest to see if any differences emerged between the groups if participants were pre-screened on both pragmatic and structural language abilities, and if these would be correlated with experimental task performance. Supplementary data (see Appendix E) suggests that verbal short-term memory, as assessed by the digit span, is strongly linked to the recall of news-like and nonsensical sentences among autistic individuals only, whereas this relationship was significant for both groups when recalling story-like sentences. The accuracy of sentence recall was not related to autistic traits in the current study, as measured by the AQ (Baron-Cohen et al., 2001), regardless of the content type. These preliminary findings suggest that cognitive abilities may play a more significant role in sentence repetition accuracy in autism, rather than autistic traits. Talli (2020) who reported that that verbal short-term memory is a strong predictor of language skills in autistic children further supports this.

Future studies should focus on investigating the relationship between short-term verbal memory and everyday language use in autistic adults. In turn, such studies could help inform longitudinal studies on ageing effects in autistic adults, who are at greater risk of a decline in verbal short-term memory that has significant impact on clinical outcomes, compared to their typically developed counterparts (Pagni et al., 2022).

5.1.3 Study 3 overview: Is autism associated with differences in melodic and linguistic expectancy?

The groups were matched on the Pitch Matching performance, and there were no statistically significant group differences between groups' frequencies depending on the level of expectation (high vs low expectancy) and the task (sentences vs melodies). In the Melody Cloze task, in the high expectancy condition, autistic participants produced more responses that were categorized as 'The most frequent', compared to the controls. However, the difference was not statistically significant after applying Bonferroni correction. Instead, it was found that the overall chi-square analysis was statistically significant, largely due to the difference in this particular category. It could be that autistic participants were more influenced by the high expectancy when producing the final note, compared to controls. Since the norms we used were based on professional musicians' responses (Fogel et al., 2015), it is plausible that this task triggered some similar neural pathways in autistic participants while singing the final note, as it would be the case for musicians. This is in line with studies suggesting that autistic individuals tend to have superior musical abilities (Foxton et al., 2003) and process auditory stimuli similarly to musicians who possess absolute pitch (Wenhart et al., 2019).

No group differences emerged in the low expectancy condition either, when producing the final note. In other words, both groups performed similarly in this condition, which could be due to both groups perceiving low expectancy condition as more demanding, and in turn, produced remarkably similar responses.

Turning back to the linguistic domain, it was expected that controls will outperform autistic individuals on the Sentence Cloze task, but such difference was not observed. This contradicts previous research reporting that autistic individuals have issues with using the sentence context when predicting the final word (Catarino et al., 2011). It is important to note that there was a statistically significant difference in the total chi-square when comparing all categories between the groups. This was due to the fact that autistic participants tended to produce more 'I don't know' responses or omit more responses than the control group. This finding is consistent with previous research that reports autistic individuals take longer to produce an answer (Gastgeb et al., 2006).

Findings on the sentence production task not only contradict our hypothesis that autistic individuals will find it more difficult to complete sentences compared to controls, but also contradict the WCC account (Happé, 2005). It is plausible that such discrepancies are found due to the differences in participants' age. Indeed, the current thesis mainly tested autistic adults, whereas the studies supporting the WCC (Happé, 2005) tested children and adolescents (e.g., Happé, 1997; Jolliffe & Baron-Cohen, 1999). In addition, the differences in experimental tasks across studies should be noted too. For instance, in the current study, participants were asked to complete a sentence with a single word only, which could be interpreted as a non-complex task compared to forming meaningful connections in the sentence context (Happe´, 2000). The current findings support those of Lopez and Leekam (2003), who emphasised that autistic individuals do not differ from controls when using sentence context. Rather, these group differences become apparent if the stimuli presented is complex, coupled with participants' low verbal abilities.

There was no group difference in participants' ratings of complete sentences and melodies, however both groups rated sentences higher than melodies. The same trend was observed depending on the level of expectancy where both groups rated the stimuli higher in the high expectancy condition, when compared to low expectancy condition. A significant interaction between the Task and the Condition has been driven by a larger discrepancy in controls' ratings between complete melodies in high expectancy condition versus low expectancy condition. In other words, autistic participants rated melodies similarly in both high and low expectancy condition, whereas controls were more influenced by level of expectancy as they rated melodies significantly lower in the Low expectancy condition, when compared to High expectancy condition. This is in line with studies reporting that autistic individuals are less influenced by the overall context (Dunn et al., 1999) than controls. It is also plausible that, since so many autistic individuals show engagement and enjoyment towards melodic stimuli (Bhatara et al., 2013), in turn, they rated melodies quite highly irrelevant to the expectancy levels.

5.1.4 Study 3a overview: Is autism associated with a "local bias" when completing sentences?

Contrary to what we expected, the groups did not differ in the number of their local response while completing a Sentence Completion Task inviting a WCC answer. This is opposed to the original study from which we used the stimuli sentences (Booth & Happé, 2010). As previously discussed in the Study 3 chapter, it could be that the difference in the scoring systems caused the difference in the results between the current and the original study. In addition, previous research suggesting a tendency towards detail-oriented processing style in autistic group has used a stimulus in the visuospatial domain (e.g., Ropar & Mitchell, 2001), which significantly differs from the linguistic domain, and partially explains the discrepancy between current results and previous findings investigating the WCC account. More recent literature suggests that autistic individuals do not have a 'global' processing deficit, but detail-oriented processing style which differs from one modality to another and is not a universal characteristic of each autistic individual (Happé & Frith, 2006).

Recent empirical studies support our findings by reporting no difference between autistic individuals and their typically developed counterparts on language tasks testing the WCC account (Happé, 2005) such as inference tests (Walęcka et al., 2022) and phonological processing (Pomper et al., 2019). It seems that the detail-oriented processing style (Tassini et al., 2022) or reduced global processing (Neufeld et al., 2020) in autistic individuals is more consistently related to the visual domain, rather than the linguistic domain. Nonetheless, autistic children benefit from using word sequences when retelling stories as part of reading instruction (Engel & Ehri, 2021). Future studies should consider individual differences in reading styles to enhance story retelling in autistic children, and other open-ended tasks.

5.2 Limitations

One of the limitations could be our sample size where ideally, we would have recruited more autistic participants. It would also be beneficial if participants were individually matched on their age and gender. Since language impairment is one of the core deficits of autism (APA, 2013), future studies should focus on examining children's language abilities using various assessments to capture the broader picture of each individual's language profile. In turn, this can impact applying speech intervention as early as possible, which has been shown to be crucial for further language development in autistic children. While the co-occurrence of autism and language impairment is not related to increased autistic symptomatology, it has been found to be related to greater receptive language impairment, and functional communication as well (Loucas et al., 2008).

5.3 Further implications

Future work should focus on developmental trajectories investigating age effects and language abilities in autistic population while using both quantitative and qualitative methods. Most of the previous research has focused on quantitative methods but qualitative approach would help investigate language abilities in everyday setting through focus groups and non-structured interviews. Such studies can help identify any confusion in the learning environment in bilingual autistic children (Hampton et al., 2017) or for children with suspected autism diagnosis showing either delayed language or 'suspicious' social behavior (McConachie et al., 2005). While quantitative based studies can enlarge our current knowledge on causes and associations, qualitative work is needed to raise the voices of autistic people where the research goes beyond 'why' questions as to understand the nature of underlying processes that differ between the autistic population and their typically developed counterparts (O'Reilly et al., 2016). Expansions present an interpretation of each utterance previously produced by the participant, involving more content and form (Fey, 1986). Cloze tasks can be used to elicit participants' expansions, and further studies are needed to explore this possibility in autistic adults to enhance their everyday communication.

Different interventions may have an impact on developing different language skills, so it is important to investigate each individual's abilities before deciding which approach would be the most beneficial. For instance, milieu teaching can be used for individuals who want to expand their vocabulary knowledge whereas responsive teaching might be better approach for improving syntactic relationships (Ingersoll, 2011) and prompting commenting and initiations (Salmon et al., 1998). In a longitudinal study by Thomas et al. (2022) investigating standardized measures of language and natural language samples as predictors of lexical and grammatical usage in autistic children, the findings suggested that early language skills as measured predicted later complexity of language usage. The secondary aim was to explore how this relationship would be influenced by the autism severity as measured by ADOS (Lord et al., 2000) and taking part in interventions (e.g., speech therapy, music therapy). It was found that ADOS severity predicted lexical usage three years later but not grammatical usage. This is in line with previous research reporting a stronger relationship between ADOS severity and vocabulary, when compared to grammar usage (Frazier et al., 2021).

Finally, intervention types may also influence later language usage, where mainstream inclusion accounted for significant amounts of variance in children's grammatical usage (Thomas et al., 2022), meaning that peers' presence can facilitate autistic children's pragmatic language use (Parsons et al., 2019a). To identify which individuals may find peer-mediated intervention most beneficial for later language use, Parsons et al. (2019b) explored autistic children's characteristics who showed large intervention effects after taking part in a peer-mediated pragmatic language intervention. The results showed that children who scored high on the Use of Context and Separation Anxiety with lower Nonverbal Communication (CCC-2), Coherence (CCC-2) and expressive vocabulary scores are more likely to benefit the most for this type of intervention. Future studies should include autistic adults in intervention programs, especially those diagnosed later in life. It would be of interest to see if autistic individuals prefer online mode of intervention, considering its accessibility and flexibility, as well as no cost due to travelling (Ashburner et al., 2016).

Autism research has grown rapidly since the start of this PhD work in 2018. Not only did the terminology change towards a less oriented 'disorder' approach (Dwyer, et al., 2022), but there was also an expressed need to include autistic individuals in autism research (e.g., Chown et al., 2017). Studies reported that a more inclusive autism research means considering not only autistic individuals' voices but also offering them a sense of belonging in the autistic community (Lam et al., 2020). Despite these proposals throughout the recent years, participatory research in autism has been scarce (den Houting et al., 2021). McVey et al. (2023) proposed an urge towards valuing neurodiversity and embracing autistic individuals' differences to avoid stigma and discrimination. More research is warranted to highlight autistic individuals' unique processing across auditory and linguistic domains, whilst aiming to produce replicable results that can be used in either clinical or everyday settings (Fusaroli et al., 2022).

5.4 Conclusions

This thesis examined perceptual abilities in a foreign language, as well as both production and perceptual abilities in a native language, while comparing controls and autistic individuals' performance. Results from three empirical chapters confirmed that there is an interesting pattern in autistic individuals' abilities when comparing melodic and linguistic domain, and distinct levels of tasks' complexities. Study 1 findings showed that autistic adults have intact, rather than enhanced, perceptual abilities in a foreign language. We did not identify a subgroup of autistic individuals who possess superior perceptual abilities. Study 2 confirmed that autistic adults tend to have difficulties with everyday communication, depending on the Content (News-like, Storylike, Nonsense), the Noise (Quiet vs Noisy condition), but not the Form (Spoken vs Sung). Finally, Study 3 only partially confirmed that autistic adults perceive levels of expectancy marginally differently across melodic and linguistic domains, and this observation was present when examining the types of responses produced as part of Sentence/Melody Cloze tasks.

Nonetheless, we did not find a local bias in autistic individuals when completing the sentences inviting the WCC account. Using several types of tasks across auditory and linguistic modalities, this thesis added novelty to the existing field and has offered potential ideas for future work primarily in clinical settings. Future studies are warranted to further investigate the uniqueness in performance in autistic children, adolescents, and adults across different modalities (e.g., auditory, visual) whilst controlling for relevant confounding variables.

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Appendices

Appendix A: Study 2 stimuli sentences

News-like sentences

1. The new musical has been seen worldwide.
2. This marks 100 years of the building.
3. The breakfast show presenter thanked listeners.
4. Thousands share experiences and support.
5. She can alter her behaviour in minutes.
6. The structure was drew up and built in 13 years.
7. The judge said it was a big factor in his ruling.
8. Seven of the victims were from the United States.
9. He is hoping to gain access after the incident.
10. The princess is a well-known international figure.
11. A hurricane was announced this afternoon on the TV.
12. The local train left the station more than five minutes ago.
13. The parents quietly crossed the dark room and approached the boy's bed.
14. The committee will meet this afternoon for a special debate.
15. The last concert given at the opera was a tremendous success.
16. Science has acquired an important place in western society.
17. Finding a job is difficult in the present economic climate.
18. The library is open every day from eight A.M. to six P.M.
19. This year's Chinese delegation was not nearly as impressive as last year's.
20. The government is planning a reform of the education program.

Story-like sentences

1. Joshua laughed at the sight of his sister.
2. He slept in a little bed by the sea.
3. Her feet, they dangle and poke into the sky.
4. She had spotted something in the reeds.
5. The waves on the sea made me wish that I flew there.
6. It was a magnificent color of a blue.
7. She was not fancy and polite like most princesses.
8. The little boy was frightened and sprang from his big chair.
9. She was curious to know why he was so excited.
10. Welcome to the dream factory, this is the first sleeping room.
11. One day an old woman ran up and down in a spotty cloak.
12. The trees and bushes were so thick; the path was not visible.
13. One winter's day they were playing inside when they heard a strange noise.
14. Alison was only five minutes away from her parents' home.
15. The cricket, did not listen, because crickets do whatever they want.
16. 'That sea merchant told us the lost forgotten Island would be right here!'
17. She was smiling ear to ear, looking for me to agree with what was said.
18. I gave a little nod, waiting nervously for someone else to start talking.
19. The wizard, who lived in the tallest tower, did magic spells for the others.
20. I knelt down closer, looking for anything that might make sense of it all.

Nonsensical sentences

1. The metal enables the heat to eat.
2. The behavior sorts the humor tearing.
3. The versed harmony recommends the driving.

4. The condition witness the chivalrous ink.
5. The rice influences the jumpy porter man.
6. The massive error trades the thick earth down the road.
7. The animal obtains the furry music game plan.
8. The laugh logs the selfish salt into the flame water.
9. The start decides the paste into the soil computer marks.
10. The existence consolidates the like mind of the cup.
11. The bite-sized distribution trains the care sight to the beard road.
12. The hapless control considers the balance of the timing.
13. The taste reconciles the motionless representative on the will.
14. The wakeful shame studies the rubbing of the chandelier marking.
15. The existence recognizes the wound of its keys as it descends.
16. The language highlights the support of the system its playing nicely.
17. The representative scripts the form to its sister after it is gone.
18. The offbeat front influences the page wrong true of itself and of herself.
19. The hideous humor preserves the shaking of the pavement and of the weather.
20. The language masters the impartial stitch of the moment of its shoulders in.

Appendix B: Study 3 Experiment 1 stimuli sentences

1. Alex brushed her teeth after every ___.
2. Jane fed her baby with some warm ___.
3. They left the dirty dishes in the ___.
4. None of his books made any ___.
5. I could not remember his ___.
6. The game was stopped when it started to ___.
7. She tied up her hair with a yellow ___.
8. The ship disappeared into the thick ___.
9. Harry scraped the cold food from his ___.
10. Karen awoke after a bad ___.
11. Susan boiled the egg in ___.
12. He had to fill his car with ___.
13. Sophie did not have any clothes to ___.
14. Yesterday Patrick canoed down the ___.
15. The children held their hands and formed a ___.
16. The bill was due at the end of the ___.
17. Carl felt sorry, but it was not his ___.
18. When the shooting started, they ran for ___.
19. Seals can swim better than they can ___.
20. Don't believe everything you ___.
21. My uncle gave my mother a big ___.
22. George could not believe his son stole a ___.

23. He was miles off the main ___.
24. If the crowd quiets down the band will ___.

25. He crept into the room without a ___.

26. For a runner, Connor is rather ___.

27. Fred sat in his chair on the back ___.

28. Harriet sang while my brother played the ___.

29. The rabbit hid in the tall ___.

30. The long test left the class ___.

31. Even their friends were left in the ___.

32. The student went home during the ___.

33. Beth liked to season her food with ___.

34. The sail got loose, so they tightened the ___.

35. The pill contained a powerful ___.

36. The rider walked his beautiful ___.

37. The apple pie had a delicious ___.

38. He disliked having to commute to the ___.

39. His view was blocked by the music ___.

40. Few nations are now ruled by a ___.

41. His ring fell into a hole in the ___.

42. You can buy anything for a ___.

43. To find the body, they had to drain the ___.

44. The wooded lake made a pretty ___.

45. Samantha cleaned the dirt from her ___.

46. After speaking Lee left the noisy ___.

47. Emily dried the bowls with a ___.

48. The difficult concept was beyond his ___.

49. The airplane went into a ___.
50. One of the scout troops got ___.

51. The surgeon tried vainly to save his ___.

52. The truck that Bill drove crashed into the ___.

53. The child went ever higher on the ___.

54. They were startled by the sudden ___.

55. The final score of the game was ___.

56. Dan caught the ball with his ___.

57. He smiled and sat down at the ___.

58. Rita slowly walked down the shaky ___.

59. Anastasia is taller than most ___.

60. We used to have people round every ___.

61. Rushing out he forgot to take his ___.

62. My aunt likes to read the daily ___.

63. He disappeared last year and has not been ___.

64. The hunter shot and killed a large ___.

65. The death of his dog was a great ___.

66. The elderly sometimes lose their ___.

67. To tune your car you need a special ___.

68. Did you want to go to the ___.

69. In the morning Alan took out the ___.

70. The car stalled because the engine failed to ___.

71. David's boss refused to give him a ___.

72. The choir sang hymns while the people ___.

73. As soon as they got in, they turned on the ___.

74. They went to the rear of the long ___.

75. Ray fell down and hurt his ___.
76. Oliver was wild when he was ___.

77. They rested under a tree in the ___.

78. The child was born with a rare ___.

79. Benjamin found that he had no spare ___.

80. The paper was too thick to ___.

81. Suzy liked to play with her toy ___.

82. Hank reached into his pocket to get the ___.

83. They liked to sleep out under the ___.

84. There's something grand about the ___.

85. The crime rate has gone up this ___.

86. The surface of the water was nice and ___.

87. The pain she felt was all in her ___.

88. Starting a business takes a lot of ___.

89. No one wanted to accuse him of ___.

90. 90. Kate slowly sank into the hot ___.

Appendix C: Study 3 Experiment 2 stimuli sentences

Sentence stems (in order of administration)	Examples of 1-point local completions	Examples of 2-point and 1-point global completions
1. I was given a pen and…[1]		
2. The sea tastes of salt and...	pepper/vinegar/sugar	water/seaweed/cold
3. Hens lay eggs and...	bacon/chips/milk/noodles	chicks/have feathers/(eggs)
4. The woman took the cup and…[1]		
5. You can get burnt by the sun and...	moon/sea/daughter/son/sand/stars/rain	fire/hot water/it hurts
6. You can feed a child bread and... [1]		
7. Little boys grow up to be men and...	women/lady	girls grow up to be women/adults/granddads
8. In the sea there are fish and...	chips	sharks/whales/lots of sea life
9. In a cave lived a bat and...	ball	bear/spiders/a caveman
10. You can go hunting with a knife and...	fork	gun/bow and arrow
11. The old shoemaker mended the shoes and...	socks/clothes/hats/shirt	boots/soles/gave them back/cleaned them
12. The fireman carried the bucket and...	spade	hose/water/ladder/put out of
13. A vet cares for cats and... [1]		
14. The night was black and...	white/blue	dark/cold (silver/had a large sword)

[1] Practice stems.

Appendix D: Supplementary material (Study 1)

Group	Background variable	**Lexical tone**	**Natural speech**	**Gliding tone analogue**
Autism (N = 21)	**Musical training**	0.10	0.10	0.09
TD (N = 42)		0.45**	0.25	0.30
Autism (N = 21)	**Age**	0.10	0.30	0.04
TD (N = 42)		0.43*	0.15	0.33*
Autism (N = 21)	**The AQ**	0.25	0.11	0.22
TD (N = 42)		0.08	0.30	0.12

Note. This table represents different correlations between relevant Background measures, and all experimental tasks in Study 1, across both groups.
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Appendix E: Supplementary material (Study 2)

Group	Background variable	**News-like**	**Nonsensical**	**Story-like**
Autism (N = 21)	**Digit span**	0.46*	0.72**	0.66**
TD (N = 42)		0.48	0.45	0.75**
Autism (N = 21)	**The AQ**	0.11	0.05	0.24
TD (N = 42)		0.32	0.11	0.04

Note. This table represents different correlations between relevant Background measures and online SRep accuracy across all three content types (Study 2) in both groups.
*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).